NI

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 69-FM-103

June 13, 1969

PRELIMINARY LUNAR ORBIT ATTITUDE SEQUENCE FOR MISSION G

Lunar Mission Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC INTERNAL NOTE NO. 69-FM-103

PROJECT APOLLO

PRELIMINARY LUNAR ORBIT ATTITUDE SEQUENCE FOR MISSION G

By L. C. Connelly
E. C. Howell
R. B. Schuck
V. W. Simmons
M. B. Vick

Mission Design Section
TRW Systems Group

June 13, 1969

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC Task Monitors
H. D. Beck
R. D. Duncan

Approved: Ronald L. Berry
Ronald L. Berry, Chief
Lunar Mission Analysis Branch

Approved: for Carl R. Huss
John P. Mayer, Chief
Mission Planning and Analysis Division

FOREWORD

The spacecraft operational trajectory for Mission G is composed of five volumes which summarize the lunar landing missions for a 3-month launch period, July, August, and September. The contents of each volume are briefly described below.

1. Volume I - Operational Mission Profile, Launched July 16, 1969: Detailed mission description of the first launch opportunity, first injection opportunity, of the July launch window. MSC IN 69-FM-98.

2. Volume II - Operational Mission Profile Trajectory Parameters, Launched July 16, 1969: Listing of significant trajectory parameters computed at selected time points during each phase of the same typical mission described in Volume I. MSC IN 69-FM-99.

3. Volume III - Mission Summaries: July 1969 Launch Window: Summaries of CSM trajectory parameters at selected time points for each launch date in the July 1969 launch window. MSC IN 69-FM-100.

4. Volume IV - Mission Summaries: August 1969 Launch Window: Summaries of CSM trajectory parameters at selected time points for each launch date in the August 1969 window. MSC IN 69-FM-101.

5. Volume V - Mission Summaries: September 1969 Launch Window: Summaries of CSM trajectory parameters at selected time points for each launch date in the September 1969 window. MSC IN 69-FM-102.

In addition to the five volumes of the operational trajectory described above, six additional documents supplement the operational trajectory.

6. Hybrid Operational Mission Profile, Launched September 13, 1969: Detailed mission description for a typical hybrid mission profile. MSC IN 69-FM-111.

7. Hybrid Operational Mission Profile Trajectory Parameters, Launched September 13, 1969: Same trajectory parameter data as Volume II except compiled from the hybrid mission. MSC IN 69-FM-112.

8. Preliminary Lunar Orbit Attitude Sequence: CSM and LM attitude sequence of events for the lunar orbit phase of the mission. MSC IN 69-FM-103. A more detailed attitude sequence for the entire mission will follow the preliminary document by 1 month.

9. TLI Ship Position and Coverage Data, July, August, and September 1969 Launch Opportunities: Injection ship positions and the launch azimuth range coverage for each day for both injection opportunities. MSC IN 69-FM-104.

10. Flight Crew Simulator Data: Provides data to satisfy flight crew and flight controller training and simulation requirements. MSC IN 69-FM-105.

11. Operational Trajectory Consumables Analysis: Prediction of the consumables usage and margins. MSC IN 69-FM-106.

CONTENTS

TABLES

FIGURES

PRELIMINARY LUNAR ORBIT ATTITUDE SEQUENCE

FOR MISSION G

By L. C. Connelly
E. C. Howell
R. B. Schuck
V. W. Simmons
M. B. Vick
Mission Design Section
TRW Systems Group

1. SUMMARY AND INTRODUCTION

1.1 General

This document presents the preliminary spacecraft attitude sequence for the lunar orbit portion of mission G. The command and service module (CSM) and lunar module (LM) activities contained in this report reflect current mission philosophy related to the respective vehicle attitude requirements. It should be emphasized that the attitude data contained in this report are preliminary in nature and subject to revision as the mission design philosophy becomes further refined. The operational attitude sequence containing the cislunar phase will be published at a later date.

The preliminary lunar orbit attitude sequence is presented in the following format:

1. Discussion of the major attitude events occuring in the mission.

2. Figures illustrating the spacecraft attitude events and activities.

3. An attitude timeline listing the chronological sequence of events (Table I). Mission event times were obtained from the Apollo 11 Preliminary Flight Plan (Reference 1).

4. Tabular data summarizing the pertinent spacecraft attitude and orbital parameters (Table II).

1.2 Trajectory Profile

The CSM and LM state vector and ephemeris data for generating the CSM solo and the docked CSM/LM attitude data were obtained from the

Lunar Mission Analysis Branch of MPAD-MSC. The LM descent and ascent trajectory parameters were furnished by the Landing Analysis Branch of MPAD-MSC, while the lunar orbit rendezvous trajectory parameters were furnished by the Orbital Mission Analysis Branch of MPAD-MSC. The complete lunar orbit phase of the mission was precision integrated on the Apollo Reference Mission Program, Version ARM07. Launch date for the mission is July 16, 1969, at 9:31:45.3 a.m., eastern daylight time, with a 72-degree launch azimuth and a Pacific translunar injection on the first opportunity.

1.3 Attitude Data Generation

For the CSM/LM docked and the CSM solo operations, the Apollo Mission Attitude Requirements (AMAR) Program was used to produce the attitude data required to define the nominal mission attitude timeline. For the two-vehicle (CSM and LM active operations) portion of the mission, the ARM07 Program was used to produce the attitude data. For the purpose of data generation, instantaneous maneuvers were assumed in reorienting the spacecraft from an existing attitude. Appropriate time intervals are provided for finite reorientations in the timeline. The maneuver times are representative only, and they are not intended to reflect actual rates.

Spacecraft attitude requirements for the various lunar orbit events have been analyzed from the systems and operational constraints document (Reference 2). Violation of any constraint when necessitated by an operational requirement will be noted in the discussion.

Spacecraft attitude data will be supplied to the Flight Planning Branch of FCSD-MSC for inclusion in the Apollo 11 flight plan. In addition, computer tapes of the lunar orbit attitude profile will be available shortly. Request for these tapes should be made through the Mission Planning Support Office of MPAD-MSC.

2. SYMBOLS

AGS	abort guidance system
AMAR	Apollo Mission Attitude Requirements Program
AOT	alignment optical telescope
APS	ascent propulsion subsystem
ARM07	Apollo Reference Mission Program, Version ARM07
CDH	constant delta altitude
CMP	command module pilot
COAS	crew optical alignment sight
CPA	closest point of approach
CSI	coelliptic sequence initiation
CSM	command and service module
DOI	descent orbit insertion
DPS	descent propulsion subsystem
FCSD-MSC	Flight Crew Support Division - Manned Spacecraft Center
g. e. t.	ground elapsed time (hr:min:sec)
G&N	guidance and navigation
HGA	high-gain antenna
IGA	inner gimbal angle
IMU	inertial measurement unit
LM	lunar module
LOI-1	first lunar orbit insertion burn
LOI-2	lunar orbit circularization burn
LR	landing radar

LS	landing site
MGA	middle gimbal angle
MPAD-MSC	Mission Planning and Analysis Division - Manned Spacecraft Center
MSFN	Manned Space Flight Network
OGA	outer gimbal angle
PDI	powered descent initiation
RCS	reaction control subsystem
REFSMMAT	reference to stable member coordinate transformation matrix
RR	rendezvous radar
SCT	scanning telescope
SPS	service propulsion system
SXT	sextant
TEI	transearth injection
TPI	terminal phase initiation
VHF	very high frequency

3. LUNAR ORBIT ATTITUDE PROFILE

This section contains a brief description of the lunar orbit attitude profile. The events are discussed in chronological order with only those mission events which affect the attitude profile being mentioned.

The mission G lunar orbit profile may be divided into five major sections:

1. First lunar orbit insertion burn (LOI-1) cutoff to CSM/LM undocking

2. CSM/LM undocking to LM landing

3. LM landing to LM lift-off

4. LM lift-off to CSM/LM docking

5. CSM/LM docking to TEI burn ignition.

The discussion will be divided into these sections with the first, third, and fifth sections being discussed revolution by revolution, while the second and fourth sections are discussed according to major events. For the purpose of this document, a vehicle revolution will be referenced to the lunar surface. The first vehicle revolution is assumed to start at LOI-1 burn cutoff and end at 180 degrees selenographic longitude. All other revolutions start and end at 180 degrees selenographic longitude.

The lunar orbit attitudes are presented referenced to the local horizontal orientation. That is: spacecraft X-axis lies along the local horizontal in the direction of motion, spacecraft Z-axis lies along the local vertical directed toward the reference body, and spacecraft Y-axis completes the right hand, orthogonal system. Figure 1 presents a method for converting a local horizontal pitch attitude into a landing site inertial pitch attitude for lunar landing site 2.

An attitude timeline listing the chronological sequence of events during the lunar orbit is presented in Table I. Detailed trajectory and attitude data for the lunar orbit are presented in Table II.

3.1 LOI-1 Burn Cutoff to CSM/LM Undocking

Detailed trajectory and attitude data for the LOI-1 burn cutoff to CSM/LM undocking portion of the lunar orbit are presented in Table II(a).

3.1.1 First revolution (Figure 2). - The LOI-1 burn is designed to insert the CSM/LM into a 60- by 170-nautical mile elliptical parking orbit around the moon. The burn is performed by the CSM service propulsion

system (SPS) engine. The CSM/LM is in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. The LOI-1 burn cutoff attitude is maintained inertially fixed until approximately six minutes prior to acquisition of MSFN line of sight. The CSM/LM is then rolled 180 degrees (right) to provide CSM S-band high-gain antenna (HGA) communications. This attitude is held inertially fixed until communications with the Manned Space Flight Network (MSFN) have been established. The vehicle is then maneuvered to a lunar observation attitude. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -45 degrees and a roll of 180 degrees. This lunar observation attitude allows observation of the CSM/LM groundtrack through the CSM hatch window and oblique views of the lunar surface through the CSM side windows. This lunar observation attitude is held locally fixed until the vehicle enters darkness. At this time, the local attitude hold is terminated, and the vehicle attitude is maintained inertially fixed to allow for a CSM inertial measurement unit (IMU) realignment. The IMU realignment to the landing site REFSMMAT occurs approximately 22 minutes after the CSM/LM enters darkness. Immediately after the CSM/LM loses MSFN line of sight, the vehicle is maneuvered back to the lunar observation attitude. This attitude is held locally fixed through completion of the first revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

3.1.2 Second revolution (Figure 3). - At the beginning of the second revolution, the spacecraft is in the locally fixed lunar observation attitude. This attitude is held locally fixed until the CSM/LM enters darkness. At this time, the local attitude hold is terminated, and the vehicle attitude is maintained inertially fixed to allow for a CSM IMU realignment. The IMU realignment to the landing site REFSMMAT occurs approximately three minutes after the CSM/LM enters darkness. Approximately 18 minutes prior to loss of MSFN line of sight, the CSM/LM is maneuvered to LOI-2 burn attitude. This attitude is held inertially fixed until just prior to the completion of the second revolution when the LOI-2 burn is performed. This circularization burn transforms the initial elliptical parking orbit into a 60-nautical mile circular orbit. The SPS burn is performed with the CSM/LM in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. The LOI-2 burn cutoff attitude is maintained inertially fixed through completion of the second revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the LOI-2 burn attitude.

3.1.3 Third revolution (Figure 4). - At the beginning of the third revolution, the spacecraft is in the inertially fixed LOI-2 burn cutoff attitude and is maintained inertially fixed until approximately six minutes prior to acquisition of MSFN line of sight when the CSM/LM is rolled 180 degrees (right) to provide CSM S-band HGA communications. This attitude is held inertially fixed until communications with MSFN have been established. The vehicle is then maneuvered to the lunar observation attitude. The lunar observation attitude is held locally fixed until the CSM/LM enters darkness. At this time the local attitude hold is terminated,

and the vehicle attitude is maintained inertially fixed to allow for a CSM IMU realignment. The IMU realignment to the landing site REFSMMAT occurs immediately after the CSM/LM enters darkness. This attitude is held inertially fixed through the completion of the third revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

3.1.4 Fourth revolution (Figure 5). - At the beginning of the fourth revolution, the spacecraft is in an inertially fixed S-band HGA communications attitude. This attitude is held inertial until approximately 16 minutes prior to acquisition of MSFN line of sight. The CSM/LM is then maneuvered to the mode I (Reference 3) landmark tracking attitude. As illustrated in Figure 6, the mode I attitude is such that the spacecraft when inertially held will be pitched two degrees below the local horizontal at 35 degrees elevation east of the landmark (approximately 90 seconds from the closest point of approach to the landmark). The spacecraft is then given a -0.3 degree per second pitch rate. The pitch rate is maintained for 264 seconds until the spacecraft is in the sleep pitch attitude. The landmark remains in the optics field of coverage for the first three minutes. The CSM/LM is then rolled 135 degrees to the sleep attitude. This attitude is held inertial through completion of the fourth revolution. Command service module S-band HGA communications will be available from the time of attaining the sleep attitude to loss of MSFN line of sight.

3.1.5 Fifth revolution (Figure 7). - At the start of the fifth revolution, the spacecraft is in the inertially fixed lunar orbit sleep attitude. An 8 hour sleep period is started approximately 25 minutes after the acquisition of MSFN line of sight. The lunar orbit sleep attitude is maintained inertially fixed through the completion of the fifth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

3.1.6 Lunar orbit sleep (Figures 8, 9, 10, 11, and 12). - The inertial lunar orbit sleep geometry is shown in Figure 8. An inertial attitude hold is used to minimize reaction control subsystem (RCS) propellant usage and to provide the required continuous CSM S-band HGA communications when line of sight to the earth exists. Also, RCS quad cold problems must be avoided. The thermal constraints may be avoided by aligning the CSM X-axis normal to the sun plus or minus some bias. The allowable bias is approximately 40 degrees. The CSM is then rolled so that direct sunlight "splits" two RCS quads. This insures that all the quads receive some heating: two quads receive direct sunlight, and the other two quads receive reflected heat from the lunar surface. A flight crew constraint is that the CSM X-axis remains in-plane during the sleep period. All of these constraints are satisfied by the inertial lunar orbit sleep attitude. The 40-degree bias and the roll to split the RCS quads is taken in such a way that communications are improved. The inertial attitude is such that the CSM is pitched -140 degrees and rolled 135 degrees from the local horizontal at the subsolar point. The longitude of the subsolar point used in calculating the attitude is the longitude

at the nominal time of starting the crew sleep period. The attitude is kept in guidance and navigation (G&N) attitude hold with a ±10-degree deadband throughout the lunar orbit sleep period. Two adjacent RCS quads are used for attitude control. The lunar orbit sleep period lasts approximately eight hours, being terminated in the ninth revolution. The inertial sleep attitude is maintained through the completion of the ninth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight in each vehicle revolution.

3.1.7 Tenth revolution (Figure 13). - At the beginning of the tenth revolution, the spacecraft is in the inertial lunar orbit sleep attitude and the crew is awake. This attitude is maintained inertially fixed through completion of the tenth revolution. The LM is occupied approximately six minutes prior to acquisition of MSFN line of sight, and the sleep attitude provides LM steerable antenna communications for the LM communications checks. The sleep attitude also satisfies the attitude requirements for a CSM IMU alignment to the updated landing site REFSMMAT which occurs immediately after the CSM/LM enters darkness. The CSM and LM S-band steerable communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

3.1.8 Eleventh revolution (Figure 14). - At the beginning of the eleventh revolution, the spacecraft is in the inertial lunar orbit sleep attitude. This attitude is held until approximately one minute after acquisition of MSFN line of sight when the CSM/LM is maneuvered to the landmark tracking attitude. This attitude is held inertially fixed until 35 degrees elevation east of the landmark when a -0.3 degree per second pitch rate is initiated. This pitch rate is maintained for 180 seconds until the landmark has passed out of the optics. Then the pitch rate is increased to -0.5 degree per second for approximately seven minutes. The pitch rate is then terminated with the CSM/LM in the undocking attitude except rolled 180 degrees for CSM S-band HGA communications. The CSM and LM S-band HGA communications will be available on the eleventh revolution from termination of the tracking pitch rate until loss of MSFN line of sight. This attitude is held inertially fixed until the AGS calibration test is performed just prior to the completion of the eleventh revolution. For the AGS calibration test, the CSM/LM is rolled 180 degrees to the undocking attitude, then yawed 14 degrees out of plane. This attitude is held inertially fixed until the test is completed early in the twelfth revolution. The CSM/LM is then yawed -14 degrees back into the orbital plane to the undocking attitude. This attitude is held inertially until undocking approximately four minutes prior to acquisition of MSFN line of sight on the twelfth revolution.

3.2 CSM/LM Undocking to LM Landing

Detailed trajectory and attitude data for both the CSM and LM during the CSM/LM undocking to LM landing portion of the lunar orbit are presented in Table II(b).

3. 2. 1 CSM/LM undocking to DOI burn ignition (Figure 15). - Undocking will occur at 98:18:00 (hr:min:sec, ground elapsed time (g. e. t.)), which is approximately 25 minutes prior to the CSM-RCS separation burn. The orientation of the vehicles is such that the LM is ahead of the CSM. The CSM is in-plane, heads down, and pitched 13. 4 degrees above the local horizontal. This attitude is the CSM inertial separation burn attitude except for a 180-degree roll angle that shades the CSM windows during the LM inspection. Following undocking, the LM will null the relative range rate after a separation distance of 40 to 50 feet is achieved. The CSM will then station keep at this distance while the LM performs a 120-degree negative roll (pilot yaw right) maneuver and a 90-degree positive pitch maneuver. This will place the LM heads down and at an attitude where the crews will be eye to eye. The command module pilot (CMP) will then inspect and photograph the LM landing gear and descent engine bell while the LM does a rotation maneuver (pilot yaw right) of two degrees per second for 360 degrees. Immediately after completion of the inspection, the LM will begin station keeping and the CSM will manually roll 180 degrees to acquire the MSFN with the HGA. These attitudes are held inertially fixed until after the CSM-RCS separation burn cutoff.

Separation is accomplished by the CSM X-axis RCS thrusters applying a ΔV of 2. 5 feet per second radially downward. This maneuver is performed at approximately 180 degrees central angle prior to descent orbit insertion (DOI). At separation burn ignition the CSM is in-plane and pitched 90 degrees above the local horizontal (plus X-axis is coincident with the radius vector). An attitude maneuver should not be required at this time since the CSM undocking attitude was the inertial separation burn attitude. The LM will have performed small translation maneuvers during the LM station keeping phase so that it will be above and slightly ahead of the CSM at separation. This will allow the LM to visually monitor the CSM-RCS separation burn while maintaining an attitude that is favorable for establishing the rendezvous radar (RR) tracking attitude which immediately follows separation. Each spacecraft will be in an attitude favorable for HGA communications during the separation burn.

Following the CSM separation burn, the CSM and LM will be maneuvered (pitched) automatically to the required attitudes for CSM SXT tracking - VHF ranging and LM RR tracking. The necessary tracking attitude points the center of the common coverage of the CSM SXT and RR transponder along the CSM-LM line of sight. The center of common coverage lies 35 degrees from the CSM plus X-axis measured toward the plus Z-axis. Likewise, the center of coverage of the LM tracking light should be pointing along the LM-CSM line of sight. The center of coverage of the tracking light lies along the LM plus Z-axis. This attitude is also the preferred attitude for LM RR coverage. For this tracking period, and for all subsequent CSM/LM tracking except during the powered descent initiation (PDI) tracking phase as discussed in Section 3. 2. 2, the CSM and LM

are initially oriented in a heads-down attitude and in a heads-up attitude, respectively. The initial attitudes of the vehicles allow for CSM SXT/RR transponder and LM RR/tracking light line-of-sight maintenance. The amount each vehicle is pitched in order to obtain the preferred track axis (vehicle-to-vehicle look-angles discussed above) is dependent upon the relative positions of the vehicles at the time of separation. Assuming that the LM is 50 feet above and 5 feet ahead of the CSM at separation, the CSM will be pitched approximately 35 degrees and the LM will be pitched approximately 0.5 degree following the CSM separation burn cutoff in order to obtain the preferred track axis.

The CSM and LM will perform an IMU realignment beginning about five minutes after sunset. Both vehicles will be in inertial attitude hold during the IMU realignments and will continue in this mode until approximately six minutes prior to LM DOI burn ignition. At this time the CSM will begin an automatic pitch maneuver to the preferred track axis discussed previously in order to monitor the LM DPS DOI burn and to provide radar transponder coverage. Also, at this time, the LM will begin a maneuver to the inertial DOI burn attitude which is a retrograde, in-plane, face-up orientation. The LM DPS DOI burn ignition occurs at 99:42:27 g.e.t.

The attitude of the CSM from the time it performs a 180-degree roll maneuver subsequent to the LM inspection until loss of MSFN line of sight is favorable for HGA communications. The attitude of the LM from the time the LM begins station keeping until loss of MSFN line of sight is favorable for HGA communications.

A relative motion plot of the two spacecraft from separation to DOI is illustrated in Figure 16. The LM is assumed to be approximately 50 feet above and 5 feet ahead of the CSM at separation. The crew procedures information presented in References 4 and 5 was utilized to develop the attitude sequences from undocking to DOI.

3.2.2 DOI burn cutoff to powered descent initiation (Figures 17 and 18). - Following cutoff of the DPS DOI burn at 99:42:55 g.e.t., the LM orients to the RR tracking attitude described in the preceding section. This tracking interval lasts for approximately 15 minutes after which the LM orients to the powered descent initiation attitude. The PDI attitude is defined at pericynthion of the descent orbit by a LM retrograde, local horizontal, and face-down orientation. The LM maintains this orientation in an inertial attitude hold until PDI.

Following DOI cutoff, the CSM continues SXT tracking - VHF ranging operations in a heads-down attitude until shortly before MSFN line-of-sight acquisition for the CSM. At this time, the automatic pitch rate is nulled and the resulting orientation maintained in an inertial attitude hold for approximately 10 minutes. This orientation provides S-band HGA communications at MSFN acquisition and continuously through the 10-minute

period. At this time, the CSM will maneuver to a heads-up SXT tracking attitude prior to PDI. The CSM S-band HGA communications are interrupted by this maneuver and will not be regained until after the LM landing.

The CSM-LM relative motion for the lunar orbit phase from DOI to LM landing is shown in Figure 18.

3.2.3 PDI burn ignition to LM landing (Figure 19). - PDI occurs at 100:38:57 g.e.t. when the DPS engine is ignited. The powered descent is a guided burn from pericynthion to landing site 2. Approximately 2 minutes after PDI, the LM rolls through 180 degrees (pilot yaw right) to a face-up orientation. The LM S-band HGA communications are available throughout the powered descent.

At PDI, the CSM nulls the automatic pitch rate of the heads-up SXT tracking attitude established prior to PDI. The resulting orientation is maintained in an inertial attitude hold for approximately two minutes. At this time, a -0.2 degree per second pitch rate is initiated and maintained until after the LM lands. The inertial hold and subsequent pitch rate insure SXT tracking throughout the powered descent. Command and service module S-band HGA communications are not available until after the LM lands.

3.3 LM Landing to LM Lift-off (CSM Solo Operations)

Detailed trajectory and attitude data for the CSM solo operations from LM landing to LM lift-off are presented in Table II(c).

3.3.1 LM landing to initiation of fourteenth revolution (Figure 20). - At LM touchdown, which occurs at 100:50:50 g.e.t., the CSM pitch rate is terminated, and the CSM is maneuvered to the landmark tracking attitude, rolled 180 degrees for communications. The CSM attitude, with respect to the local horizontal orientation, is a pitch of 67.0 degrees and a roll of 180 degrees.

This inertial attitude satisfies the requirements for the IMU realignment to the landing site REFSMMAT, which occurs approximately 10 minutes after LM touchdown.

The CSM attitude is held inertially fixed through the completion of the thirteenth revolution. Command and service module S-band HGA communications will be available from the maneuver at LM touchdown until loss of MSFN line of sight.

3.3.2 Undocked lunar landmark tracking (Figure 21). - During the undocked landmark tracking periods, LM blockage, which obscured part of the CSM optics during docked sightings, is no longer a problem. For this reason, mode III type landmark tracking will be used for the undocked

landmark sightings (Reference 3). The spacecraft attitude, with respect to the local horizontal orientation during undocked sightings, is a pitch of -22 degrees. The geometry of the mode III type landmark tracking is shown in Figure 21. The landmark enters the scanning telescope (SCT) field of coverage 100 seconds before the closest point of approach (CPA) (32 degrees elevation) and exits the SXT field of coverage 56 seconds past the CPA (49.7 degrees elevation). The landmark remains in the SXT field of coverage for 146 seconds within the acceptable mark region. This should be adequate time to obtain the required five marks. It should be pointed out, if trouble occurs in obtaining the marks, additional tracking time can be made available by adding a small pitch rate near the end of the tracking period. The optical blind zone constraint may be satisfied, as in the docked sightings, by rolling the spacecraft as the landmark is approached to assure a minimum trunnion angle of at least 10 degrees.

3.3.3 Fourteenth revolution (Figure 22). - At the beginning of the fourteenth revolution, the CSM is in the inertially fixed landmark tracking attitude, rolled 180 degrees. Approximately 2 minutes after acquisition of MSFN line of sight, the CSM is rolled 180 degrees to the mode III type landmark tracking attitude. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -22 degrees. This attitude is held locally fixed through the completion of tracking of the LM. At this time, approximately nine minutes before entering darkness, the CSM maneuvers to the plane-change attitude, yawed 45 degrees. This attitude is held inertially fixed until the completion of the IMU realignment to the plane change REFSMMAT, which occurs approximately five minutes after entering darkness. Approximately 10 minutes before loss of MSFN line of sight, the CSM is maneuvered to the plane-change attitude. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -68.0 degrees, a yaw of 88.3 degrees, and a roll of -83.8 degrees. This attitude is held inertially fixed through the completion of the fourteenth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight until loss of MSFN line of sight, except when tracking the LM during landmark tracking.

3.3.4 Fifteenth revolution (Figure 23). - At the beginning of the fifteenth revolution, the CSM is in the inertially fixed plane-change attitude. The CSM plane-change attitude is held inertially fixed through the plane-change burn which occurs at 105:09:17 g.e.t. The CSM plane-change burn attitude is held inertially fixed until approximately one minute after the burn cutoff, when the CSM maneuvers to the attitude for IMU realignment to the landing site REFSMMAT. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -88.1 degrees, a yaw of 45.0 degrees, and a roll of -89.8 degrees. The IMU realignment begins approximately 14 minutes prior to loss of MSFN line of sight. The CSM IMU realignment attitude is held inertially fixed until approximately six minutes after loss of MSFN line of sight, when the CSM maneuvers to the lunar orbit sleep attitude. This attitude is held inertially fixed through the completion of the fifteenth revolution. The CSM S-band HGA communications will be available from the acquisition of MSFN line of sight until the loss of MSFN line of sight.

3.3.5 Second lunar orbit sleep (Figures 24, 25, 26, 27, 28, and 29). - The CSM attitude during the second lunar orbit sleep period will be the same attitude as that for the first lunar orbit sleep period as illustrated in Figure 8. This sleep period consists of a four-hour rest period, and a four-hour period in which no activities are currently planned for the CSM, followed by another four-hour rest period and terminating at the time of the IMU realignment to the launch site REFSMMAT in the twenty-second revolution. The inertial lunar orbit sleep attitude is such that the CSM is pitched -140 degrees and rolled 135 degrees from the local horizontal orientation at the subsolar point. The longitude used in calculating the attitude is the longitude at the subsolar point in the eighteenth revolution. The inertial sleep attitude is maintained through the completion of the twenty-first revolution. Command and service module S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight in each vehicle revolution.

3.3.6 Twenty-second revolution (Figure 30). - At the beginning of the twenty-second revolution, the CSM is in the inertially fixed lunar orbit sleep attitude. This inertially fixed attitude satisfies the requirement for an IMU realignment to the lunar launch site REFSMMAT, which occurs approximately seven minutes after the CSM enters darkness. This attitude is held inertially fixed through the completion of the twenty-second revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until loss of MSFN line of sight.

3.3.7 Twenty-third revolution (Figure 31). - At the beginning of the twenty-third revolution, the CSM is in the inertially fixed lunar orbit sleep attitude. The CSM attitude is maintained inertially fixed until approximately seven minutes before entering darkness. The CSM is then maneuvered to the initial attitude for LM lift-off support, rolled 180 degrees. The spacecraft attitude is a pitch of -43.0 degrees and a roll of 180 degrees from the local horizontal orientation. The CSM attitude is held inertially fixed through the completion of the twenty-third revolution. This attitude satisfies the requirements for an IMU realignment to the launch site REFSMMAT, which occurs approximately two minutes prior to entering darkness. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until loss of MSFN line of sight.

3.3.8 Twenty-fourth revolution until LM lift-off (Figure 32). - At the beginning of the twenty-fourth revolution, the CSM is in the inertially fixed LM lift-off support attitude, rolled 180 degrees for communications. The attitude is maintained inertially fixed until approximately 20 minutes prior to LM lift-off, when the CSM is rolled 180 degrees to the initial attitude to support LM lift-off. At LM lift-off, the CSM is pitched 60 degrees below the local horizontal orientation. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the LM lift-off support attitude.

3.4 LM Lift-off to CSM/LM Docking

Detailed trajectory and attitude data for both the CSM and LM during the LM lift-off to CSM/LM docking portion of the lunar orbit are presented in Table II(d).

3.4.1 Lift-off to insertion (Figure 33). - Ascent ignition occurs at 122:28:11 g.e.t. The powered ascent is a guided ascent propulsion subsystem (APS) burn to a targeted 9-nautical mile by 45-nautical mile ellipse. The LM orientation during the burn provides LM S-band HGA communications.

Prior to ascent ignition, the CSM is oriented to provide RR tracking for ascent monitoring. At ascent ignition, the CSM initiates a -0.2 degree per second pitch rate to insure RR tracking throughout the ascent burn. The CSM S-band HGA communications are available approximately five minutes after ascent ignition.

3.4.2 Insertion burn cutoff to CDH burn ignition (Figures 34 and 35). - Cutoff of the APS insertion burn occurs at 122:35:35 g.e.t. with the LM pitched -2.6 degrees from the local horizontal orientation. The LM maintains this burnout attitude inertially fixed and performs an IMU realignment approximately 10 minutes after burn cutoff and 4 minutes after the LM enters lunar umbra. At completion of the realignment, the LM orients to the heads up RR tracking attitude in preparation for a tracking period starting 18 minutes after insertion burn cutoff.

The CSM, at insertion burn cutoff nominally continues the -0.2 pitch rate established at LM lift-off until time to reorient for the SXT tracking - VHF ranging period 18 minutes after burn cutoff. With this pitch rate, the steerable antenna loses earth line of sight as a result of the CSM blockage approximately seven minutes after insertion. The tracking attitude/attitude rate for the following LM tracking period results in nominal HGA coverage until MSFN occultation at 19 minutes 13 seconds into the period. The CSM and LM tracking times for the nominal rendezvous were obtained from Reference 6. The CSM-LM relative motion during rendezvous is shown in Figure 35.

The CSM and LM terminate the 23-minute tracking and begin preparations for the coelleptic sequence initiation (CSI) burn. Both spacecraft are in darkness and out of MSFN line of sight. The LM HGA communications are nominal from insertion to loss of MSFN line of sight.

The pre-CSI preparations consist of the LM and CSM orienting to the inertial CSI and mirror image (MI) CSI burn attitude, respectively. The MI burn attitude is a means of providing CSM backup capability for the LM rendezvous burns from insertion to the final braking maneuvers. (The CSM nominally performs the docking maneuver.) The MI burn attitude involves aligning the CSM propulsion system (RCS or SPS) in a thrusting direction opposite the LM burn orientation. Ignition for the MI burn is

scheduled three minutes after the nominal time of ignition for the LM burn.

The LM CSI burn is performed with the RCS plus Z-axis thrusters. Ignition occurs at 123:26:27 g. e. t. with a burn time of approximately 8 seconds. The nominal burn attitude at ignition is pitched 90. 0 degrees from the local horizontal orientation. This attitude corresponds to a heads-up, face-forward direction for the crew.

The backup burn attitude for the CSM, which is maintained inertially fixed until the LM burn is confirmed, is retrograde and heads-down at the nominal LM ignition time.

After completion of the burn, each vehicle maintains its respective attitude at cutoff, inertially fixed until maneuvering to required attitudes for a 39-minute tracking period beginning 6 minutes after the burn.

The CSM and LM acquire line of sight to MSFN approximately 26 minutes and 29 minutes, respectively, after starting the tracking period. The CSM attitude profile from this time until termination of the tracking period is incompatible with HGA pointing requirements for MSFN coverage. A roll maneuver of 180 degrees is performed at the completion of the LM tracking period to acquire MSFN through the HGA. The resulting attitude is held inertially fixed through the completion of the LM constant delta altitude (CDH) burn.

The LM HGA communications during the period from MSFN line-of-sight acquisition to completion of the CDH burn is acceptable. The LM orients to the inertial CDH burn attitude after terminating CSM tracking. The burn attitude at ignition (124:24:25 g. e. t.) is identical to the CSI burn attitude (i. e. heads up and face forward). The RCS minus X-axis thrusters perform the burn which results in a radially downward thrust direction. The CSM is not scheduled for a backup CDH maneuver. As noted previously, the CSM attitude at the end of the preceeding tracking period (after a 180-degree roll) is inertially fixed until the start of the next LM tracking period following the CDH burn.

3. 4. 3 CDH burn cutoff to CSM/LM docking (Figure 36). - The CSM and LM begin another tracking period four minutes after CDH burn cutoff at 124:24:27 g. e. t. Both spacecraft hold their respective attitudes at CDH burn termination until orienting to the required tracking attitude. The tracking period is 19 minutes in duration and is followed by terminal phase initiation (TPI) burn preparations.

The CSM orients to the inertial MI TPI burn attitude as part of the pre-TPI operations, which is pitched -151. 7 degrees from the local horizontal orientation at TPI ignition. This attitude permits a boresight alignment of the LM along the CSM plus X-axis at ignition. The CSM maintains the MI burn attitude until the LM TPI burn is confirmed as nominal.

The LM maneuvers to the inertial TPI burn attitude following the tracking period termination. The burn attitude at ignition is pitched 117.9 degrees from the local horizontal orientation. Ignition is at 125:02:46 g.e.t. (24 minutes 42 seconds after the LM enters darkness) with a nominal burn time of 13.5 seconds. The plus Z-axis RCS thrusters perform the burn.

Communications through the CSM and LM S-band steerable antenna are satisfactory throughout the period from CDH burn cutoff to loss of MSFN by lunar occultation.

Following TPI burn termination, both spacecraft initiate a maneuver to the nominal SXT tracking - VHF ranging attitude (CSM) and RR tracking attitude (LM). The CSM is initially heads down and the LM initially heads up at the required tracking attitude. As a result of the LM catch-up rate following TPI, the CSM and LM attitude direction during the post-TPI tracking period results in a heads-up attitude for the CSM and a heads-down attitude for the LM. A roll maneuver of 180 degrees is required for both vehicles before final docking preparations can begin. This maneuver is executed after the completion of the LM braking burns.

Prior to the initial braking burn at 125:44:04 g.e.t., the CSM terminates the automatic SXT tracking - VHF ranging program and begins line-of-sight tracking of the LM along the CSM plus X-axis. This boresight tracking attitude is maintained from this point on to the final docking maneuvers. The LM continues RR tracking along the plus Z-axis during the coasts between the braking maneuvers. This LM tracking attitude profile is compatible with the braking burns since the thrust direction for the burns is along the plus Z-axis.

Note that the first LM braking burn occurs at a CSM-LM relative range of 3000 feet. The braking maneuver at the one-nautical mile separation distance was not required in the rendezvous simulation. The final braking maneuver occurs at a relative range of 100 feet at ignition. At cutoff, the range is approximately 90 feet and the closing rate is 0.23 feet per second. The CSM continues line-of-sight maintenance to the LM along the plus X-axis. The LM maintains the plus Z-axis towards the CSM until a separation distance of 50 feet is reached. At this point, the LM executes a pitch-down maneuver of 90 degrees. This maneuver aligns the plus X-axis of each spacecraft towards the other. A 180-degree roll is then executed by the CSM and LM in preparation for the final docking maneuvers. Both spacecraft then fly formation while the CSM performs the closing maneuvers as noted earlier. These include rolling the CSM to properly align the docking index. The final docking attitude relative to the sun positions the line-of-sight direction to the sun 85 degrees from the CSM minus X-axis. This attitude satisfies the sunlight constraint imposed on the active vehicle during docking.

Docking is assumed to be completed at 126:00:00 g.e.t. The CSM/LM docking attitude was designed to satisfy the lighting condition just noted

and consequently does not provide nominal HGA coverage for either the CSM or LM upon acquisition of MSFN line-of-sight.

3.5 CSM/LM Docking to TEI

Detailed trajectory and attitude data for the CSM/LM docking to TEI portion of the lunar orbit are presented in Table II(e).

3.5.1 CSM/LM docking to completion of twenty-sixth revolution (Figure 37). - The completion of the CSM/LM docking maneuver occurs at 126:00:00 g.e.t. This attitude is held inertially fixed through post docking checks. The spacecraft is then maneuvered to the LM jettison attitude rolled 180 degrees. This attitude is held inertial through completion of the twenty-sixth revolution and this attitude provides CSM and LM HGA communications to loss of sight of MSFN.

3.5.2 Twenty-seventh revolution (Figure 38). - At the beginning of the twenty-seventh revolution, the CSM/LM is in the inertially fixed LM jettison attitude rolled 180 degrees. Approximately 10 minutes later, the spacecraft is rolled 180 degrees to the LM jettison attitude. The LM jettison attitude is such that the CSM is pitched 180 degrees from the local horizontal orientation at 90 degrees east selenographic longitude. The LM jettison occurs at 127:59:47 g.e.t. The jettison attitude is held inertial until approximately 10 minutes after LM jettison when the spacecraft is maneuvered to the transearth injection (TEI) burn attitude rolled 180 degrees. This attitude is held inertial through completion of the twenty-seventh revolution. This attitude satisfies the requirements for an IMU realignment to the launch site REFSMMAT which occurs immediately after the CSM enters darkness. The CSM S-band HGA communications will be available from the maneuver to the TEI burn attitude rolled 180 degrees to the loss of MSFN line of sight.

3.5.3 Twenty-eight revolution (Figure 39). - At the beginning of the twenty-eight revolution, the CSM is in the inertially fixed TEI burn attitude rolled 180 degrees. This attitude satisfies the requirements for an IMU realignment to the launch site REFSMMAT. The IMU realignment occurs immediately after the CSM enters darkness. This attitude is maintained inertially until the CSM is rolled 180 degrees to the TEI burn attitude, approximately five minutes before loss of MSFN line of sight. This attitude is held inertially fixed through completion of the twenty-eighth revolution. Command and service module S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the TEI burn attitude.

3.5.4 Start of twenty-ninth revolution to TEI (Figure 40). - Shortly after the CSM begins the twenty-ninth revolution, the TEI burn occurs. The TEI burn is an SPS burn which boosts the CSM from its approximately 60-nautical mile circular lunar orbit into the transearth trajectory. The burn is performed with the CSM in a posigrade attitude, and the crew is heads down to afford visual reference with the lunar surface. The TEI burn ignition occurs at 131:28:43 g.e.t.

Table I. Mission G Lunar Orbit Event Timeline

Mission Time (hr:min:sec)	Event
75:55:03	LOI-1 ignition
76:01:08	LOI-1 cutoff, inertial attitude hold
76:13:00	Roll 180 deg for communications, inertial attitude hold
76:19:44	Acquire MSFN line of sight
76:25:00	Maneuver to lunar observation attitude, local attitude hold
77:03:00	Terminate orbital rate, inertial attitude hold
77:03:07	Enter lunar umbra
77:25:00	Begin IMU realignment
77:44:47	Lose MSFN line of sight
77:45:00	Maneuver to lunar observation attitude, local attitude hold
77:49:08	Enter sunlight
78:27:57	Acquire MSFN line of sight
79:11:00	Terminate orbital rate, inertial attitude hold
79:11:44	Enter lunar umbra
79:15:00	Begin IMU realignment
79:35:00	Maneuver to LOI-2 burn attitude, inertial attitude hold
79:53:05	Lose MSFN line of sight
79:57:44	Enter sunlight
80:12:01	LOI-2 ignition
80:12:15	LOI-2 cutoff, inertial attitude hold
80:32:00	Roll 180 deg for communications, inertial attitude hold
80:38:07	Acquire MSFN line of sight
80:43:00	Maneuver to lunar observation attitude, local attitude hold
81:10:00	Terminate orbital rate, inertial attitude hold
81:10:35	Enter lunar umbra
81:11:00	Begin IMU realignment
81:49:43	Lose MSFN line of sight

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
81:56:48	Enter sunlight
82:32:00	Maneuver to landmark tracking attitude, inertial attitude hold
82:36:17	Acquire MSFN line of sight
82:52:11	Begin -0.3 deg/sec pitch rate for landmark tracking
82:56:35	Terminate pitch rate, roll 135 deg to sleep attitude
83:09:07	Enter lunar umbra
83:48:14	Lose MSFN line of sight
83:55:16	Enter sunlight
84:34:37	Acquire MSFN line of sight
85:00:00	Start crew sleep period
85:07:42	Enter lunar umbra
85:46:25	Lose MSFN line of sight
85:53:54	Enter sunlight
86:32:49	Acquire MSFN line of sight
87:06:16	Enter lunar umbra
87:44:44	Lose MSFN line of sight
87:52:23	Enter sunlight
88:31:17	Acquire MSFN line of sight
89:04:49	Enter lunar umbra
89:42:58	Lose MSFN line of sight
89:51:00	Enter sunlight
90:29:32	Acquire MSFN line of sight
91:03:19	Enter lunar umbra
91:41:18	Lose MSFN line of sight
91:49:31	Enter sunlight
92:27:56	Acquire MSFN line of sight
93:00:00	Terminate sleep period
93:01:57	Enter lunar umbra
93:39:37	Lose MSFN line of sight

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
93:48:05	Enter sunlight
94:25:39	Acquire MSFN line of sight
95:00:25	Enter lunar umbra
95:01:00	Begin IMU realignment
95:37:14	Lose MSFN line of sight
95:46:38	Enter sunlight
96:23:49	Acquire MSFN line of sight
96:25:00	Maneuver to landmark sighting attitude, inertial attitude hold
96:48:27	Begin -0.3 deg/sec pitch rate for landmark tracking
96:51:27	Begin -0.5 deg/sec pitch rate
96:58:12	Terminate pitch rate in undocking pitch attitude, inertial attitude hold
96:59:04	Enter lunar umbra
97:06:00	Deploy LM landing gear
97:35:41	Lose MSFN line of sight
97:45:14	Enter sunlight
97:54:00	Maneuver for AGS calibration test, inertial attitude hold
98:05:00	Maneuver to undocking attitude, inertial attitude hold
98:18:00	Undocking, inertial attitude hold
98:20:39	LM maneuvers to inspection attitude, inertial attitude hold except for 360 deg roll (pilot yaw right) maneuver
98:22:09	CSM, LM acquire MSFN line of sight
98:23:39	LM begins station keeping, inertial attitude hold
98:25:09	CSM rolls 180 deg for S-band high-gain communications, inertial attitude hold
98:43:14	CSM separation burn ignition, inertial attitude hold
98:43:29	CSM separation burn cutoff
98:48:09	CSM maneuvers to SXT tracking - VHF ranging attitude; LM maneuvers to RR tracking attitude, line-of-sight maintenance

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
98:57:35	CSM enters lunar umbra
98:57:36	LM enters lunar umbra
99:03:00	CSM, LM begin IMU realignment, inertial attitude hold
99:34:04	CSM loses MSFN line of sight
99:34:06	LM loses MSFN line of sight
99:37:00	LM maneuvers to DOI burn attitude, inertial attitude hold
99:38:19	CSM maneuvers to SXT tracking - VHF ranging attitude, line-of-sight maintenance
99:42:27	LM DOI burn ignition, inertial attitude hold; CSM maneuver to SXT tracking - VHF ranging attitude, line-of-sight maintenance
99:42:55	LM DOI burn cutoff, LM maneuver to RR tracking attitude
99:43:47	CSM enters sunlight
99:43:49	LM enters sunlight
99:57:55	LM terminates tracking, maneuver to PDI attitude, inertial attitude hold
100:20:26	CSM acquires MSFN line of sight, terminate tracking, inertial attitude hold
100:22:30	LM acquires MSFN
100:30:26	CSM maneuvers to heads-up SXT tracking - VHF ranging attitude, line-of-sight maintenance
100:38:57	LM PDI; CSM terminates tracking pitch rate, inertial attitude hold
100:40:57	LM 180-degree roll (Pilot yaw right); CSM continues SXT tracking, begins -0.2 deg/sec pitch rate
100:50:50	LM landing
100:50:51	Maneuver to landmark tracking attitude, rolled 180 deg, inertial attitude hold
100:56:02	Enter lunar umbra
101:00:00	Begin IMU realignment

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
101:32:17	Lose MSFN line of sight
101:42:27	Enter sunlight
101:53:13	Begin 14th revolution
102:18:32	Acquire MSFN line of sight
102:20:00	Roll 180 deg to landmark tracking attitude, local attitude hold
102:46:00	Maneuver to plane change attitude, yawed 45 deg, inertial attitude hold
102:54:44	Enter lunar umbra
103:00:00	Begin IMU realignment
103:20:00	Maneuver to plane change attitude, inertial attitude hold
103:30:35	Lose MSFN line of sight
103:40:59	Enter sunlight
103:51:27	Begin 15th revolution
104:16:50	Acquire MSFN line of sight
104:53:16	Enter lunar umbra
105:09:17	CSM plane change
105:10:00	Maneuver to IMU realignment attitude, inertial attitude hold
105:15:00	Begin IMU realignment
105:28:31	Lose MSFN line of sight
105:35:00	Maneuver to sleep attitude, inertial attitude hold
105:39:37	Enter sunlight
105:49:40	Begin 16th revolution
106:15:06	Acquire MSFN line of sight
106:51:44	Enter lunar umbra
107:26:59	Lose MSFN line of sight
107:38:07	Enter sunlight
108:13:24	Acquire MSFN line of sight
108:50:23	Enter lunar umbra

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
109:25:13	Lose MSFN line of sight
109:36:45	Enter sunlight
110:11:39	Acquire MSFN line of sight
110:48:50	Enter lunar umbra
111:23:33	Lose MSFN line of sight
111:35:14	Enter sunlight
112:10:01	Acquire MSFN line of sight
112:47:31	Enter lunar umbra
113:21:44	Lose MSFN line of sight
113:33:54	Enter sunlight
114:08:20	Acquire MSFN line of sight
114:45:57	Enter lunar umbra
115:20:02	Lose MSFN line of sight
115:32:27	Enter sunlight
116:06:41	Acquire MSFN line of sight
116:44:31	Enter lunar umbra
117:18:25	Lose MSFN line of sight
117:30:54	Enter sunlight
117:39:02	Begin 22nd revolution
118:05:02	Acquire MSFN line of sight
118:43:10	Enter lunar umbra
118:50:00	Begin IMU realignment
119:16:38	Lose MSFN line of sight
119:29:33	Enter sunlight
119:37:16	Begin 23rd revolution
120:02:37	Acquire MSFN line of sight
120:35:00	Maneuver to initial attitude for LM lift-off support, rolled 180 deg, inertial attitude hold
120:40:00	Begin IMU realignment
120:41:40	Enter lunar umbra

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
121:14:22	Lose MSFN line of sight
121:28:01	Enter sunlight
121:35:29	Begin 24th revolution
122:01:00	Acquire MSFN line of sight
122:08:00	Roll 180 deg to LM lift-off support attitude, inertial attitude hold
122:28:11	LM lift-off; CSM initiates -0.2 deg/sec pitch rate for RR tracking
122:35:25	Insertion burn cutoff, inertial attitude hold
122:40:18	CSM enters lunar umbra
122:41:24	LM enters lunar umbra
122:44:25	LM begins IMU realignment, continue inertial hold in insertion burnout attitude
122:53:25	LM completes IMU realignment, CSM and LM begins SXT tracking-VHF ranging and RR tracking, respectively
123:12:38	CSM loses MSFN line of sight
123:14:45	LM loses MSFN line of sight
123:16:27	CSM and LM terminate tracking, CSM maneuvers to MI CSI burn attitude, inertial attitude hold; LM maneuvers to CSI burn attitude, inertial attitude hold
123:26:27	CSI burn ignition (RCS plus Z-axis two jets)
123:26:35	CSM enters sunlight
123:27:13	CSI burn cutoff, inertial attitude hold
123:30:14	LM enters sunlight
123:33:13	CSM and LM begin SXT tracking-VHF ranging and RR tracking, respectively
123:59:21	CSM acquires MSFN line of sight
124:02:18	LM acquires MSFN line of sight
124:12:25	CSM and LM terminate tracking, CSM inertial attitude hold; LM maneuvers to CDH burn attitude, inertial attitude hold
124:24:25	CDH burn ignition (RCS minus X-axis four jets)

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
124:24:27	CDH burn cutoff, inertial attitude hold
124:28:27	CSM and LM begin SXT tracking-VHF ranging and RR tracking, respectively
124:38:51	CSM enters umbra
124:39:04	LM enters umbra
124:47:27	CSM and LM terminate tracking, CSM maneuvers to MI TPI burn attitude, inertial attitude hold; LM maneuvers to TPI burn attitude, inertial attitude hold
125:02:46	TPI burn ignition (RCS plus Z-axis two jets)
125:03:10	TPI burn cutoff, CSM and LM maneuver to SXT tracking-VHF ranging and RR tracking attitude, respectively
125:10:35	LM loses MSFN line of sight
125:11:01	CSM loses MSFN line of sight
125:25:08	CSM enters sunlight
125:25:38	LM enters sunlight
125:44:04	LM braking burn ignition (RCS minus Z-axis two jets), CSM-LM range = 3000 ft
125:44:14	Braking burn cutoff, CSM and LM resume tracking
125:45:17	LM braking burn ignition (RCS minus Z-axis two jets), CSM-LM range = 1500 ft
125:45:26	Braking burn cutoff, CSM and LM resume tracking
125:46:55	LM braking burn ignition (RCS minus Z-axis two jets), CSM-LM range = 500 ft
125:47:00	Braking burn cutoff, CSM and LM resume tracking
125:48:15	LM braking burn ignition (RCS minus Z-axis two jets), CSM-LM range = 100 ft
125:48:20	Braking burn cutoff, CSM-LM range = 90 ft, range rate = -0.23 ft/sec
125:51:00	CSM and LM maneuver to docking attitude, CSM-LM range = 50 ft
125:52:43	CSM and LM roll 180 deg, LM pitch 180 deg, CSM and LM maintain line of sight along CSM X-axis and LM Z-axis to CSM-LM range of 50 ft

Table I. Mission G Lunar Orbit Event Timeline (Continued)

Mission Time (hr:min:sec)	Event
125:57:41	CSM and LM acquire MSFN line of sight
126:00:00	CSM/LM docking (CSM active), inertial attitude hold
126:06:00	Maneuver to LM jettison rolled 180 deg, inertial attitude hold
126:37:25	Enter lunar umbra
127:09:25	Lose MSFN line of sight
127:23:36	Enter sunlight
127:40:00	Maneuver to LM jettison attitude, inertial attitude hold
127:55:39	Acquire MSFN line of sight
127:59:47	LM jettison
128:10:00	Maneuver to TEI burn attitude rolled 180 deg, inertial attitude hold
128:35:51	Enter lunar umbra
128:36:00	Begin IMU realignment
129:07:35	Lose MSFN line of sight
129:22:05	Enter sunlight
129:53:51	Acquire MSFN line of sight
130:34:27	Enter lunar umbra
130:35:00	Begin IMU realignment
131:00:00	Maneuver to TEI burn attitude, inertial attitude hold
131:05:29	Lose MSFN line of sight
131:20:36	Enter sunlight
131:28:43	TEI burn ignition

Table II. Spacecraft Attitude and Trajectory Data for Lunar Orbit
(a) LOI-1 Burn Cutoff to CSM/LM Undocking

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
76:01:08	LOI-1 cutoff, inertial attitude hold	61.5	0.3	165.0	-170.4	-15.3	-2.0	-132.6	-15.3	-2.0	No line of sight		145.2	-155.2		
76:13:00	Roll 180 deg for communications, inertial attitude hold	80.6	1.0	128.8	-134.3	-15.3	178.0	-132.6	-15.3	178.0	No line of sight		145.2	24.8		
76:25:00	Maneuver to lunar observation attitude, local attitude hold	110.8	1.2	94.0	-45.0	0.0	180.0	-78.1	0.0	180.0	34.3	-179.6	157.2	-179.5		
77:03:00	Terminate orbital rate, inertial attitude hold	167.2	-0.1	-5.8	-45.0	0.0	180.0	-177.5	0.0	180.0	134.3	-179.6	103.3	-0.2		
77:25:00	Begin IMU realignment	132.5	-1.1	-63.1	12.1	0.0	180.0	-177.5	0.0	180.0	134.7	-179.6	No line of sight			
77:45:00	Maneuver to lunar observation attitude, local attitude hold	81.3	-1.1	-119.9	-45.0	0.0	180.0	68.7	0.0	180.0	No line of sight		No line of sight			
79:11:00	Terminate orbital rate, inertial attitude hold	167.5	-0.1	-5.5	-45.0	0.0	180.0	-176.1	0.0	180.0	134.0	-179.5	104.7	-0.2		
79:15:00	Begin IMU realignment	165.0	-0.3	-15.7	-34.7	0.0	180.0	-176.1	0.0	180.0	134.1	-179.6	No line of sight			
79:35:00	Maneuver to LOI-2 burn attitude, inertial attitude hold	129.0	-1.1	-68.1	72.8	-2.4	0.1	-120.7	-2.4	0.1	79.1	0.8	No line of sight			
80:12:01	LOI-2 ignition	58.7	-0.1	-177.7	-178.0	-2.4	0.1	-120.7	-2.4	0.1	No line of sight		159.9	-174.0		
80:12:15	LOI-2 cutoff, inertial attitude hold	58.7	-0.1	-178.5	-177.2	-2.4	0.1	-120.7	-2.4	0.1	No line of sight		159.9	-174.0		
80:32:00	Roll 180 deg for communications, inertial attitude hold	58.7	1.0	121.5	-117.3	-2.4	-179.9	-120.7	-2.4	-179.9	No line of sight		159.9	6.0		
80:43:00	Maneuver to lunar observation attitude, local attitude hold	58.4	1.2	88.0	-45.0	0.0	180.0	-81.7	0.0	180.0	40.2	-179.3	161.1	-179.4		
81:10:00	Terminate orbital rate, inertial attitude hold	57.7	0.2	5.7	-45.0	0.0	180.0	-163.7	0.0	180.0	122.6	-179.4	116.9	-0.2		
81:11:00	Begin IMU realignment	57.7	0.1	2.7	-42.0	0.0	180.0	-163.7	0.0	180.0	122.6	-179.4	No line of sight			
82:32:00	Maneuver to landmark tracking attitude, inertial attitude hold	58.6	1.1	116.1	-63.3	0.0	0.0	-71.0	0.0	0.0	No line of sight		150.4	0.4		
82:52:11	Begin -0.3 deg/sec pitch rate for landmark tracking on G1	58.1	1.1	54.6	-2.1	0.0	0.0	-71.0	0.0	0.0	30.6	1.1	150.4	0.4	20.8	20.7
82:56:35	Terminate pitch rate, roll 135 deg to sleep attitude, inertial attitude hold	58.0	0.9	41.2	-67.9	0.0	135.0	-150.2	0.0	135.0	109.8	-134.4	130.4	44.7	-55.0	127.4
85:00:00	Start crew sleep period	58.8	0.6	25.4	-53.2	0.0	135.0	-150.2	0.0	135.0	111.0	-134.4	130.3	44.7		
93:00:00	Terminate sleep period	57.7	0.3	3.8	-36.0	0.0	135.0	-150.2	0.0	135.0	115.2	-133.9	130.0	44.7		
95:01:00	Begin IMU realignment	57.7	0.1	-4.7	-28.7	0.0	135.0	-150.2	0.0	135.0	116.3	-133.7	No line of sight			
96:25:00	Maneuver to landmark tracking attitude, inertial attitude hold	58.6	1.2	99.6	-73.3	0.0	0.0	-89.8	0.0	0.0	56.4	1.5	169.7	1.0		
96:48:27	Begin -0.3 deg/sec pitch rate for landmark tracking on 130	57.9	0.8	28.2	-2.1	0.0	0.0	-89.8	0.0	0.0	56.7	1.5	169.7	1.0	16.1	20.7
96:51:27	Begin -0.5 deg/sec pitch rate	57.8	0.6	19.0	-47.0	0.0	0.0	-143.8	0.0	0.0	110.8	1.4	136.3	179.7	-170.9	37.2
96:58:12	Terminate pitch rate in undocking pitch attitude, inertial attitude hold	57.7	0.2	-1.5	131.1	0.0	0.0	13.8	0.0	0.0	46.7	178.2	66.1	0.2		
97:06:00	Deploy LM landing gear	57.6	-0.3	-25.3	154.8	0.0	0.0	13.8	0.0	0.0	46.5	178.2	No line of sight			
97:54:00	Maneuver for AGS calibration test, inertial attitude hold	58.6	-0.4	-171.5	-59.4	14.0	180.0	13.8	14.0	180.0	No line of sight		66.9	174.1		
98:05:00	Maneuver to undocking attitude, inertial attitude hold	58.8	0.3	155.0	-26.0	0.0	180.0	13.8	0.0	180.0	No line of sight		66.2	-179.8		

Table II. Spacecraft Attitude and Trajectory Data for Lunar Orbit
(b) CSM/LM Undocking to LM Landing

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Look Angles to Other Vehicle	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
98:18:00	Undocking, inertial attitude hold	CSM	58.7	1.0	115.5	13.4	0.0	180.0	13.8	0.0	180.0	No line of sight		66.2	-179.8	0.0	0.0
		LM	58.7	1.0	115.5	-166.6	0.0	120.0	-166.2	0.0	120.0	No line of sight		113.8	59.8	0.0	0.0
98:20:39	LM maneuver to inspection attitude, continue inertial attitude hold except for 360 deg roll (pilot yaw) maneuver	CSM	58.6	1.1	107.4	21.4	0.0	180.0	13.8	0.0	180.0	No line of sight		66.2	-179.8	4.1	0.0
		LM	58.6	1.1	107.4	-68.5	0.0	0.0	-76.2	0.0	0.0	No line of sight		156.2	0.5	94.1	180.0
98:25:09	CSM roll 180 deg for HGA communications, inertial attitude hold	CSM	58.5	1.2	93.7	35.1	0.0	0.0	13.8	0.0	0.0	46.1	178.1	66.2	0.2	12.3	-179.9
		LM	58.5	1.2	93.7	-54.9	0.0	0.0	-76.2	0.0	0.0	43.9	1.9	156.2	0.5	102.3	180.0
98:43:14	CSM separation burn ignition, inertial attitude hold	CSM	58.0	0.9	38.7	90.0	0.0	0.0	13.8	0.0	0.0	45.9	178.1	66.2	0.2	7.1	-179.9
		LM	58.0	0.9	38.7	0.0	0.0	0.0	-76.2	0.0	0.0	44.1	2.0	156.2	0.4	97.1	180.0
98:43:29	CSM separation burn cutoff	CSM	58.0	0.9	37.9	90.7	0.0	0.0	13.8	0.0	0.0	45.9	178.1	66.2	0.2	4.9	180.0
		LM	58.0	0.9	37.9	0.7	0.0	0.0	-76.2	0.0	0.0	44.1	2.0	156.2	0.4	94.9	180.0
98:48:09	CSM maneuver to SXT tracking-VHF ranging attitude; LM maneuver to RR tracking attitude, line-of-sight maintenance	CSM	57.8	0.7	23.7	139.7	0.0	0.0	48.6	0.0	0.0	80.6	178.6	31.4	0.4	35.0	180.0
		LM	57.9	0.7	23.7	14.7	0.0	0.0	-76.4	0.0	0.0	44.5	2.0	156.4	0.5	90.0	180.0
99:03:00	CSM, LM begin IMU realignment, inertial attitude hold	CSM	57.2	-0.2	-21.6	174.3	0.0	0.0	38.1	0.0	0.0	69.7	178.5	No line of sight		35.0	180.0
		LM	57.6	-0.2	-21.6	49.3	0.0	0.0	-86.9	0.0	0.0	55.3	1.7	No line of sight		90.0	180.0
99:37:00	LM maneuver to DOI burn attitude, inertial attitude hold	CSM	58.0	-1.1	-125.3	-112.3	0.0	0.0	8.1	0.0	0.0	No line of sight		No line of sight		71.8	180.0
		LM	58.1	-1.1	-125.2	163.5	0.0	0.0	-76.0	0.0	0.0	No line of sight		No line of sight		167.6	180.0
99:38:19	CSM maneuver to SXT tracking-VHF ranging attitude, line-of-sight maintenance	CSM	58.1	-1.1	-129.3	-148.0	0.0	0.0	-31.7	0.0	0.0	No line of sight		No line of sight		35.0	180.0
		LM	58.2	-1.1	-129.2	167.5	0.0	0.0	-76.0	0.0	0.0	No line of sight		No line of sight		170.6	180.0
99:42:27	LM DOI burn ignition, inertial attitude hold; CSM maneuver to SXT tracking-VHF ranging attitude, line-of-sight maintenance	CSM	58.3	-1.0	-141.8	-145.7	0.0	0.0	-41.8	0.0	0.0	No line of sight		No line of sight		35.0	180.0
		LM	58.3	-1.0	-141.7	-178.7	0.0	0.0	-74.7	0.0	0.0	No line of sight		No line of sight		180.0	0.0
99:42:55	LM DOI burn cutoff, LM maneuver to RR tracking attitude	CSM	58.3	-1.0	-143.3	-145.2	0.0	0.0	-42.7	0.0	0.0	No line of sight		No line of sight		35.0	180.0
		LM	58.3	-0.9	-143.2	89.7	0.0	0.0	167.8	0.0	0.0	No line of sight		No line of sight		90.0	180.0
99:57:55	LM terminate tracking, maneuver to PDI attitude, inertial attitude hold	CSM	59.0	-0.1	171.1	-96.4	0.0	0.0	-96.4	0.0	0.0	No line of sight		119.5	0.0	35.0	180.0
		LM	50.3	-0.1	171.5	49.1	0.0	180.0	106.5	0.0	180.0	No line of sight		26.4	0.0	1.0	-1.4
100:20:26	CSM acquire MSFN line of sight, terminate tracking, inertial attitude hold	CSM	59.0	1.1	102.7	-15.8	0.0	0.0	-27.0	0.0	0.0	4.5	161.2	107.1	0.0	35.0	180.0
		LM	22.2	1.1	100.8	119.7	0.0	180.0	106.5	0.0	180.0	137.7	-2.1	26.4	0.0	11.4	180.0
100:30:26	CSM maneuver to heads-up SXT tracking-VHF ranging attitude, line-of-sight maintenance	CSM	58.6	1.2	72.2	-0.6	0.0	0.0	-42.2	0.0	0.0	11.1	7.5	122.2	0.0	35.0	180.0
		LM	11.8	1.2	67.9	152.4	0.0	180.0	106.5	0.0	180.0	137.7	-2.1	26.4	0.0	3.7	0.0
100:38:57	LM PDI; CSM terminate tracking pitch rate, inertial attitude hold	CSM	58.2	1.0	46.3	7.4	0.0	0.0	-60.0	0.0	0.0	29.0	2.9	140.1	0.4	35.0	180.0
		LM	8.2	1.0	39.5	-179.3	0.0	180.0	106.5	0.0	180.0	137.7	-2.1	26.4	0.0	21.5	0.0
100:40:57	LM 180-deg roll (pilot yaw right); CSM continue SXT tracking, begin -0.2 deg/sec pitch rate	CSM	58.0	1.0	40.3	13.5	0.0	0.0	-60.0	0.0	0.0	29.0	2.9	140.1	0.0	40.8	180.0
		LM	7.9	0.9	33.3	171.8	0.0	0.0	91.3	0.0	0.0	122.3	180.0	11.2	180.0	12.3	180.0
100:50:50	LM landing	CSM	57.5	0.5	10.2	-74.9	0.0	0.0	-178.4	0.0	0.0	147.6	2.7	101.5	180.0	83.8	180.0
		LM	0.0	0.7	23.7	90.0	0.0	0.0	0.0	0.0	0.0	32.4	176.7	78.6	0.0	83.7	180.0

Table II. Spacecraft Attitude and Trajectory Data
(c) LM Landing to LM Lift-off (CSM Solo)

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
100:50:51	CSM maneuver to landmark tracking attitude, rolled 180 deg, inertial attitude hold	57.6	0.5	10.1	67.3	0.0	180.0	-36.2	0.0	180.0	5.6	-164.8	116.3	-179.8		
101:00:00	Begin IMU realignment	57.3	-0.1	-17.8	95.2	0.0	180.0	-36.2	0.0	180.0	5.8	-165.2	No line of sight			
102:20:00	Roll 180 deg to landmark tracking attitude, local attitude hold	59.1	1.2	98.6	-22.0	0.0	0.0	-36.2	0.0	0.0	6.2	14.3	116.4	0.2		
102:46:00	Maneuver to plane change attitude, yawed 45 deg, inertial attitude hold	57.7	0.7	19.5	-165.6	45.0	-89.5	101.3	45.0	-89.5	116.5	-123.2	48.6	-29.2		
103:00:00	Begin IMU realignment	57.2	-0.2	-23.2	-123.0	45.0	-89.5	45.0	-0.3	0.1	116.3	-122.9	No line of sight			
103:20:00	Maneuver to plane change attitude, inertial attitude hold	57.4	-1.2	-84.2	-68.0	88.3	-83.8	1.7	-0.2	0.0	89.4	-130.9	No line of sight			
105:09:17	CSM plane change	57.1	-0.8	-56.9	-96.3	88.3	-83.8	1.7	-0.2	0.0	89.3	-130.0	No line of sight			
105:10:00	Maneuver to IMU realignment attitude, inertial attitude hold	57.2	-0.9	-59.2	-88.1	45.0	-89.8	45.0	-0.3	0.1	115.4	-121.9	No line of sight			
105:15:00	Begin IMU realignment	57.2	-1.0	-74.4	-72.9	45.0	-89.8	89.6	45.0	-89.8	115.4	-121.8	No line of sight			
105:35:00	Maneuver to sleep attitude, inertial attitude hold	58.2	-0.9	-135.4	96.9	0.0	135.0	-161.4	0.0	135.0	No line of sight		No line of sight			
118:50:00	Begin IMU realignment	57.2	-0.4	-35.9	-9.8	0.0	135.0	-161.4	0.0	135.0	128.5	-131.8	No line of sight			
120:35:00	Maneuver to CSM attitude for LM lift-off support, rolled 180 deg, inertial attitude hold	57.7	0.4	4.4	-43.6	0.0	180.0	-153.9	0.0	180.0	121.7	-177.0	137.1	-0.3		
120:40:00	Begin IMU realignment	57.5	0.1	-10.9	-28.4	0.0	180.0	-153.9	0.0	180.0	121.9	-177.0	137.1	-0.3		
122:08:00	Roll 180 deg to attitude for LM lift-off support, inertial attitude hold	59.0	1.1	81.2	-121.2	0.0	0.0	-153.9	0.0	0.0	122.4	3.1	137.0	179.7		

Table II. Spacecraft Attitude and Trajectory Data for Lunar Orbit
(d) LM Lift-off to CSM/LM Docking

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Look Angles to Other Vehicle	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
122:28:11	LM lift-off; CSM initiates -0.2 deg per second pitch rate for RR tracking	CSM	59.7	0.7	19.8	-60.0	0.0	0.0	153.9	0.0	180.0	122.7	3.2	137.0	180.0	75.8	180.0
		LM	0.0	0.7	23.7	88.5	0.0	0.0	1.5	0.0	0.0	32.8	174.3	67.7	0.0	51.1	180.0
122:35:25	Insertion burn cutoff, inertial attitude hold	CSM	57.6	0.3	-2.3	-124.9	0.0	0.0	-119.2	0.0	180.0	150.1	174.6	50.1	179.7	36.8	180.0
		LM	8.2	0.6	13.5	-2.6	0.0	0.0	-102.7	0.0	0.0	71.6	2.8	171.8	1.6	5.1	0.0
122:44:25	LM begin IMU realignment, continue inertial hold	CSM	57.2	-0.2	-29.7	154.4	0.0	0.0	11.2	0.0	0.0	42.0	176.0	57.9	0.3	43.2	0.0
		LM	13.0	0.0	-16.2	27.1	0.0	0.0	-102.7	0.0	0.0	71.8	2.8	171.8	1.6	23.0	180.0
122:53:25	LM complete IMU realignment, CSM and LM maneuver to SXT tracking-VHF ranging and RR tracking attitude, respectively	CSM	57.1	-0.7	-57.2	-128.9	0.0	0.0	60.5	0.0	0.0	91.1	177.3	No line of sight		35.0	180.0
		LM	20.9	-0.5	-45.6	94.5	0.0	0.0	-64.5	0.0	0.0	34.0	4.8	No line of sight		90.0	180.0
123:16:27	CSM and LM terminate tracking, CSM maneuver to MI CSI burn attitude, inertial attitude hold; LM maneuver to CSI burn attitude, inertial attitude hold	CSM	57.8	-1.0	-127.4	149.6	0.0	0.0	-91.0	0.0	0.0	No line of sight		No line of sight		41.1	0.0
		LM	40.7	-1.1	-118.3	59.2	0.0	0.0	-172.3	0.0	0.0	No line of sight		No line of sight		57.5	180.0
123:26:27	CSI burn ignition	CSM	58.3	-0.7	-157.9	180.0	0.0	0.0	-91.0	0.0	0.0	No line of sight		No line of sight		10.1	0.0
		LM	43.3	-0.8	-149.2	90.0	0.0	0.0	-172.3	0.0	0.0	No line of sight		No line of sight		88.6	180.0
123:27:13	CSI burn cutoff, inertial attitude hold	CSM	58.4	-0.7	-160.2	-177.7	0.0	0.0	-91.0	0.0	0.0	No line of sight		160.1	0.0	7.8	0.0
		LM	43.3	-0.8	-151.6	91.0	0.0	0.0	-173.7	0.0	0.0	No line of sight		No line of sight		89.6	180.0
123:33:13	CSM and LM maneuver to SXT tracking-VHF ranging and RR tracking attitude, respectively	CSM	58.7	-0.4	-178.5	-134.6	0.0	0.0	-66.2	0.0	0.0	No line of sight		135.3	0.0	35.0	180.0
		LM	43.1	-0.5	-170.3	92.2	0.0	0.0	168.8	0.0	0.0	No line of sight		99.7	179.8	90.0	180.0
124:12:25	CSM and LM terminate tracking, CSM inertial attitude hold; LM maneuver to CDH burn attitude, inertial attitude hold	CSM	58.7	1.1	62.4	-132.3	0.0	180.0	177.4	0.0	180.0	152.1	-174.1	108.2	-0.2	35.0	0.0
		LM	42.8	1.1	67.5	52.7	0.0	0.0	7.6	0.0	0.0	38.0	175.5	61.6	0.2	45.2	180.0
124:24:25	CDH burn ignition	CSM	58.1	0.8	25.9	-95.9	0.0	180.0	177.4	0.0	180.0	152.3	-174.1	108.2	-0.3	70.5	0.0
		LM	43.0	0.8	30.1	90.0	0.0	0.0	7.6	0.0	0.0	37.8	175.5	61.6	0.2	80.6	180.0
124:24:27	CDH burn cutoff, inertial attitude hold	CSM	58.1	0.8	25.7	-95.7	0.0	180.0	177.4	0.0	180.0	152.4	-174.1	108.2	-0.3	70.6	0.0
		LM	43.0	0.8	30.0	89.2	0.0	0.0	6.6	0.0	0.0	36.8	175.4	62.6	0.2	79.8	180.0
124:28:27	CSM and LM maneuver to SXT tracking-VHF ranging and RR tracking attitude, respectively	CSM	57.8	0.6	13.5	-130.8	0.0	0.0	130.2	0.0	0.0	160.1	171.9	61.0	179.7	35.0	180.0
		LM	42.9	0.6	17.5	100.2	0.0	0.0	5.2	0.0	0.0	35.3	175.2	64.0	0.3	90.0	180.0
124:47:27	CSM and LM terminate tracking, CSM maneuver to MI TPI burn attitude, inertial attitude hold; LM maneuver to TPI burn attitude, inertial attitude hold	CSM	57.1	-0.5	-44.4	161.7	0.0	0.0	4.9	0.0	0.0	34.6	175.1	No line of sight		37.2	0.0
		LM	42.4	-0.4	-41.7	70.2	0.0	0.0	-83.9	0.0	0.0	54.3	3.0	No line of sight		53.9	180.0
125:02:46	TPI burn ignition	CSM	57.3	-1.0	-91.1	-151.7	0.0	0.0	4.9	0.0	0.0	34.4	175.1	No line of sight		0.0	0.0
		LM	42.5	-1.0	-89.5	117.9	0.0	0.0	-83.9	0.0	0.0	54.5	3.0	No line of sight		91.2	180.0
125:03:10	TPI burn cutoff, CSM and LM maneuver to SXT tracking-VHF ranging and RR tracking attitude, respectively	CSM	57.3	-1.1	-92.3	-116.3	0.0	0.0	39.1	0.0	0.0	68.5	177.0	No line of sight		35.0	180.0
		LM	42.5	-1.1	-90.7	117.0	0.0	0.0	-85.9	0.0	0.0	56.6	3.3	No line of sight		90.0	180.0
125:44:04	LM braking burn ignition, CSM-LM range = 3000 ft	CSM	59.1	0.3	143.1	-23.4	0.2	0.1	7.9	0.2	0.1	No line of sight		61.3	0.0	34.2	180.0
		LM	58.7	0.3	143.1	-149.5	-0.1	0.0	-118.3	-0.1	0.0	No line of sight		172.5	179.0	88.1	180.0
125:44:14	Braking burn cutoff, CSM and LM resume tracking	CSM	59.1	0.3	142.6	-22.9	-0.2	0.1	7.9	0.2	0.1	No line of sight		61.3	0.0	34.1	180.0
		LM	58.8	0.3	142.6	148.8	-0.1	0.0	-118.1	-0.1	0.0	No line of sight		172.7	179.0	88.2	180.0
125:45:17	LM braking burn ignition, CSM-LM range = 1500 ft	CSM	59.2	0.4	139.4	-54.8	0.2	0.1	-27.2	0.2	0.2	No line of sight		96.5	0.2	0.0	0.0
		LM	59.0	0.4	139.4	-143.6	-0.2	0.1	-116.0	-0.2	0.1	No line of sight		174.8	179.4	90.1	180.0
125:45:26	Braking burn cutoff, CSM and LM resume tracking	CSM	59.2	0.4	139.0	-54.4	0.2	0.1	-27.3	0.2	0.1	No line of sight		96.5	0.3	0.0	0.0
		LM	59.0	0.4	139.0	-142.9	-0.2	0.1	-115.8	-0.2	0.1	No line of sight		175.0	179.4	90.2	180.0
125:46:55	LM braking burn ignition, CSM-LM range = 500 ft	CSM	59.2	0.5	134.5	-49.4	0.2	0.0	-27.0	0.2	0.0	No line of sight		96.3	0.3	1.3	180.0
		LM	59.1	0.5	134.5	-138.6	-0.2	0.1	-116.0	-0.2	0.1	No line of sight		174.7	179.1	89.7	180.0
125:47:00	Braking burn cutoff, CSM and LM resume tracking	CSM	59.2	0.5	134.2	-49.4	0.2	0.0	-27.0	0.2	0.0	No line of sight		96.3	0.3	1.4	180.0
		LM	59.1	0.5	134.2	-138.3	-0.2	0.1	-115.9	-0.2	0.1	No line of sight		174.9	179.1	89.8	180.0
125:48:15	LM braking burn ignition, CSM-LM range = 100 ft	CSM	59.2	0.6	130.4	-45.3	0.2	0.0	-26.7	0.2	0.0	No line of sight		95.9	0.3	0.0	0.0
		LM	59.2	0.6	130.4	-134.1	-0.1	0.1	-115.5	-0.1	0.1	No line of sight		175.2	178.8	89.7	180.0
125:48:20	Braking burn cutoff, CSM-LM range = 90 ft, range rate = -0.23 ft/sec	CSM	59.2	0.6	130.2	-45.0	0.2	0.0	-26.7	0.2	0.0	No line of sight		95.9	0.3	1.1	180.0
		LM	59.2	0.6	130.2	-133.8	-0.1	0.1	-115.4	-0.1	0.1	No line of sight		175.3	178.7	89.7	180.0
125:52:43	CSM and LM roll 180 deg, LM pitch 180 deg, CSM and LM maintain line of sight along CSM X-axis and LM Z-axis to range of 50 ft	CSM	59.2	0.8	116.8	-30.8	0.1	-179.8	-26.1	0.1	-179.8	No line of sight		95.3	180.0	0.0	0.0
		LM	59.2	0.8	116.8	77.6	0.1	179.8	64.9	0.1	179.8	No line of sight		4.3	-178.7	90.0	180.0
126:00:00	CSM/LM docking, inertial attitude hold	CSM	59.1	1.0	94.7	-8.8	0.5	120.3	-25.8	0.5	120.3	4.3	26.6	95.0	-120.0	0.0	0.0
		LM	59.1	1.0	94.7	171.2	-0.5	179.7	154.2	-0.5	179.7	175.7	-146.6	85.0	0.0	0.0	0.0

Table II. Spacecraft Attitude and Trajectory Data for Lunar Orbit
(e) CSM/LM Docking to TEI

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
126:00:00	CSM/LM docking, inertial attitude hold	59.1	1.0	94.7	-8.8	0.5	120.3	-25.8	0.5	120.3	4.3	26.6	95.0	-120.0		
126:06:00	Maneuver to LM jettison attitude rolled 180 deg, inertial attitude hold	58.9	1.1	76.5	-165.4	0.0	180.0	159.4	0.0	180.0	170.8	-162.0	90.1	-0.2		
127:40:00	Maneuver to LM jettison attitude, inertial attitude hold	59.1	0.2	150.1	120.1	0.0	0.0	159.4	0.0	0.0	No line of sight		90.1	179.8		
127:59:47	LM jettison	59.1	1.0	90.0	-180.0	0.0	0.0	159.4	0.0	0.0	171.8	20.8	90.1	179.8		
128:10:00	Maneuver to TEI burn attitude rolled 180 deg, inertial attitude hold	58.7	1.1	58.9	109.4	13.2	1.5	57.8	13.2	1.5	85.4	176.5	17.3	-49.3		
128:36:00	Begin IMU realignment	57.3	0.1	-20.3	-171.7	13.2	1.5	57.8	13.2	1.5	84.9	176.6	No line of sight			
130:35:00	Begin IMU realignment	57.3	0.0	-22.8	-170.2	13.2	1.5	57.8	13.2	1.5	83.8	176.8	No line of sight			
131:00:00	Maneuver to TEI burn attitude, inertial attitude hold	56.8	-1.1	-99.1	-94.1	13.2	-178.5	57.8	13.2	-178.5	83.4	-3.1	No line of sight			
131:28:43	TEI burn ignition .	58.0	-0.3	173.3	-6.8	13.2	-178.5	57.8	13.2	-178.5	No line of sight		17.4	131.0		

Table III. Mission G Lunar Orbit IMU Matrices; Launch Date July 16, 1969; 72-Degree Launch Azimuth[a]

Landing Site

$$\begin{bmatrix} \overline{X} \\ \overline{Y} \\ \overline{Z} \end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ 0.79231226 & 0.00276275 & 0.61010955 \\ 0.56181423 & -0.39325903 & -0.72781326 \\ 0.23792032 & 0.91942360 & -0.31313609 \end{bmatrix}$$

Plane Change

$$\begin{bmatrix} \overline{X} \\ \overline{Y} \\ \overline{Z} \end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ 0.00279829 & -0.65180537 & 0.75838114 \\ -0.39330923 & -0.69797996 & -0.59844118 \\ 0.91940200 & -0.29660369 & -0.25831421 \end{bmatrix}$$

Launch Site

$$\begin{bmatrix} \overline{X} \\ \overline{Y} \\ \overline{Z} \end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ 0.64987382 & 0.00504055 & 0.76002533 \\ 0.70078374 & -0.39107705 & -0.59662453 \\ 0.29422116 & 0.92034413 & -0.25768308 \end{bmatrix}$$

[a]The components of the unit vectors are listed in column format.

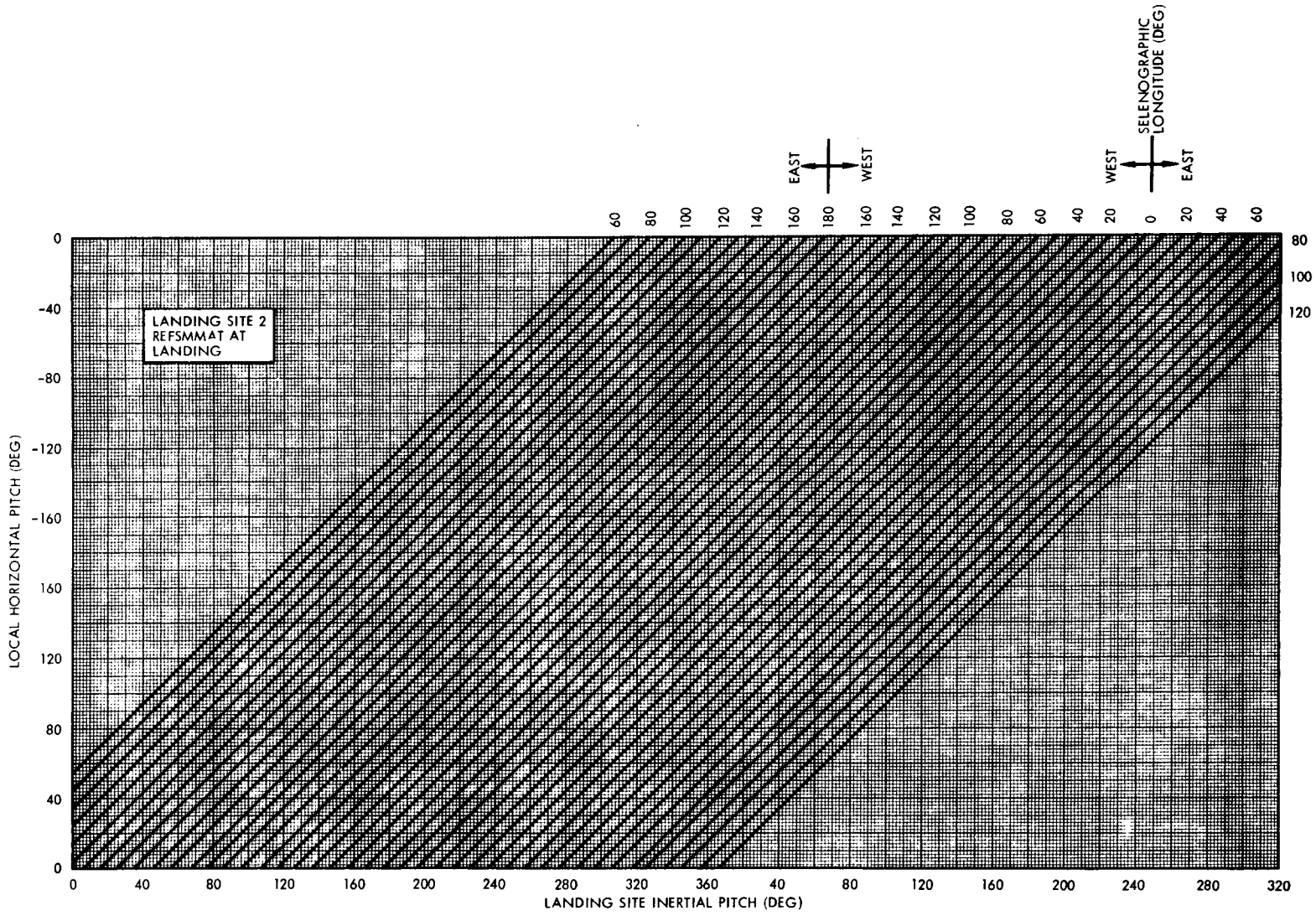

Figure 1. Local Horizontal Pitch as a Function of Landing Site Inertial Pitch for Landing Site 2

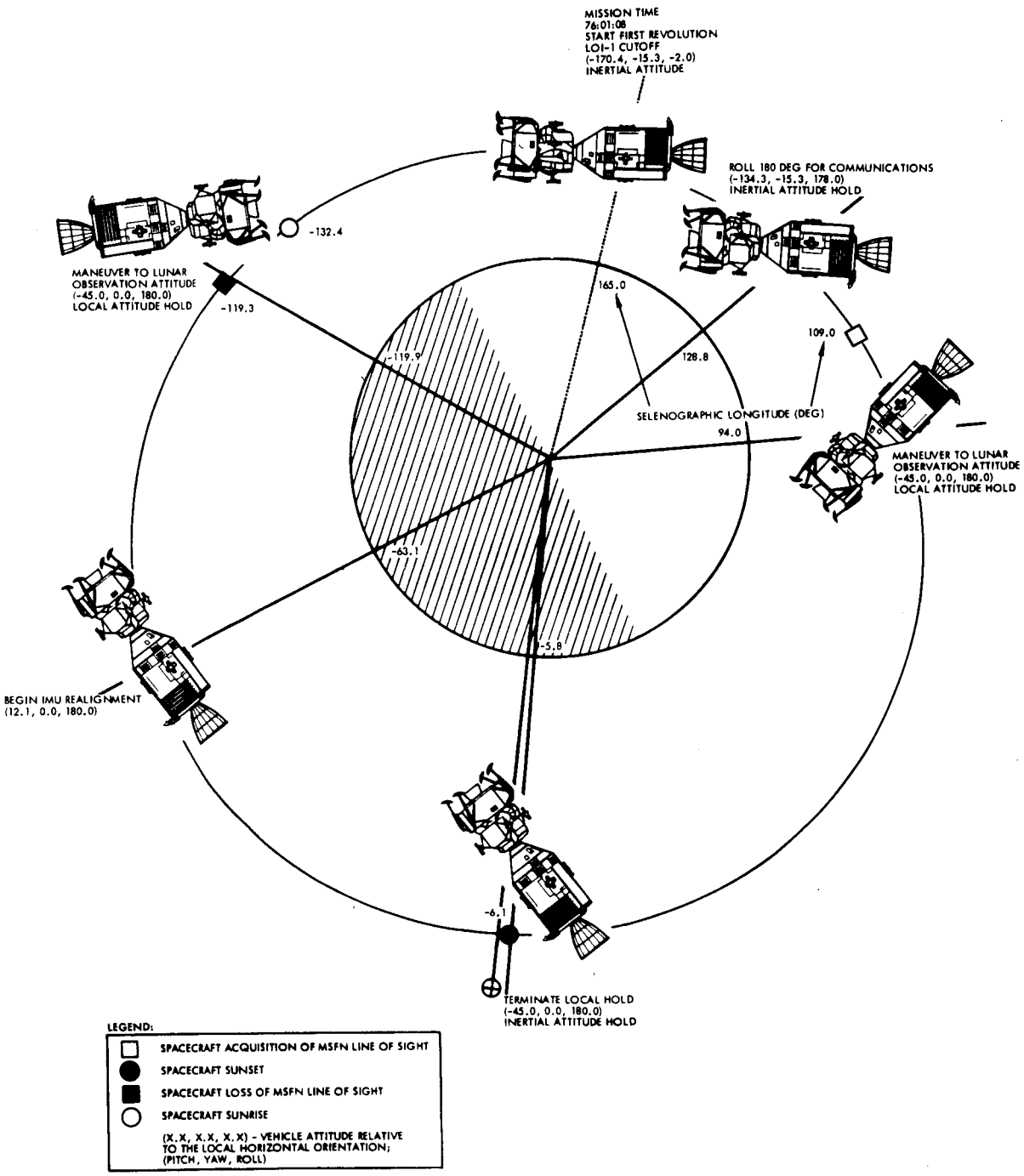

Figure 2. First Revolution Major Events and Attitudes

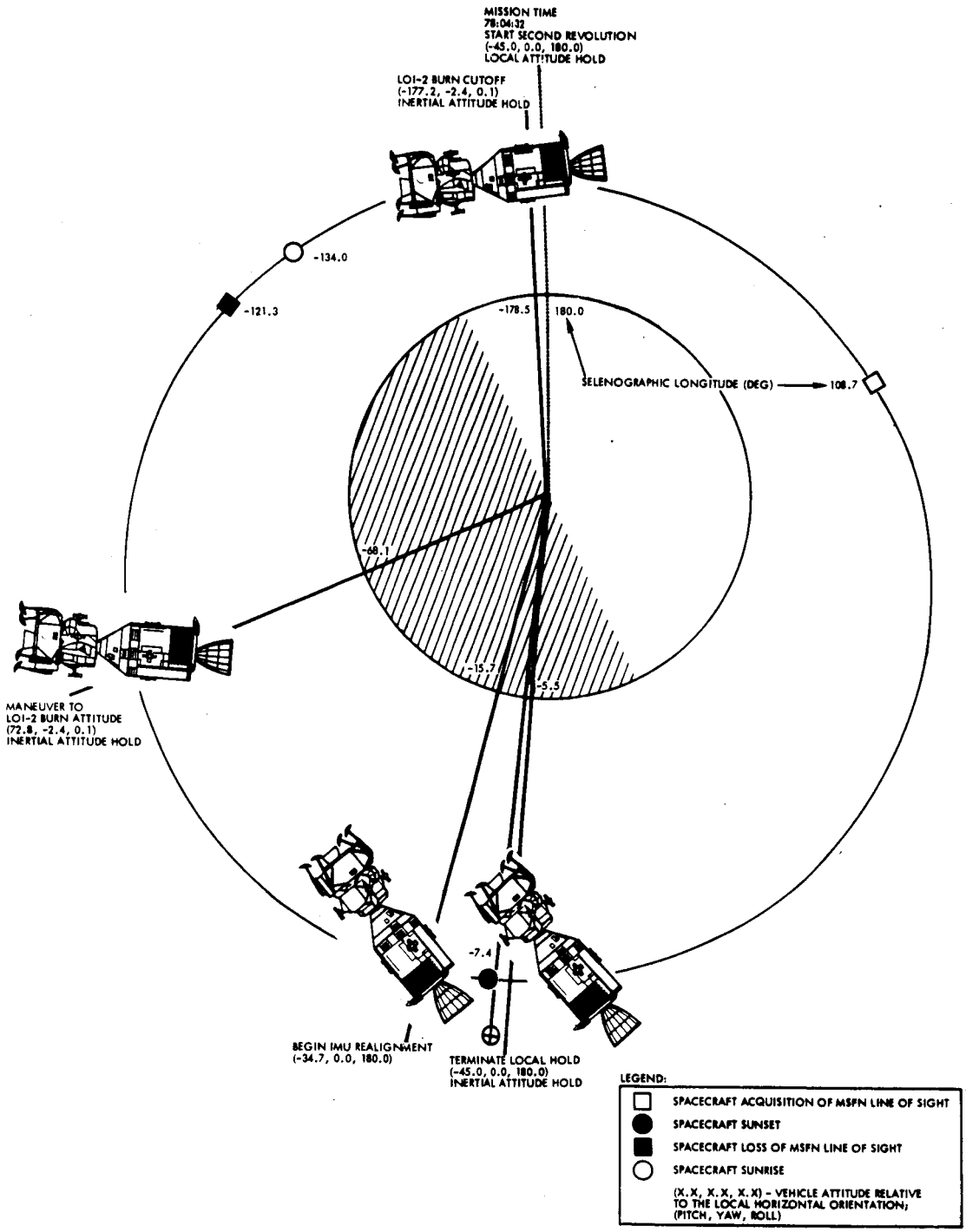

Figure 3. Second Revolution Major Events and Attitudes

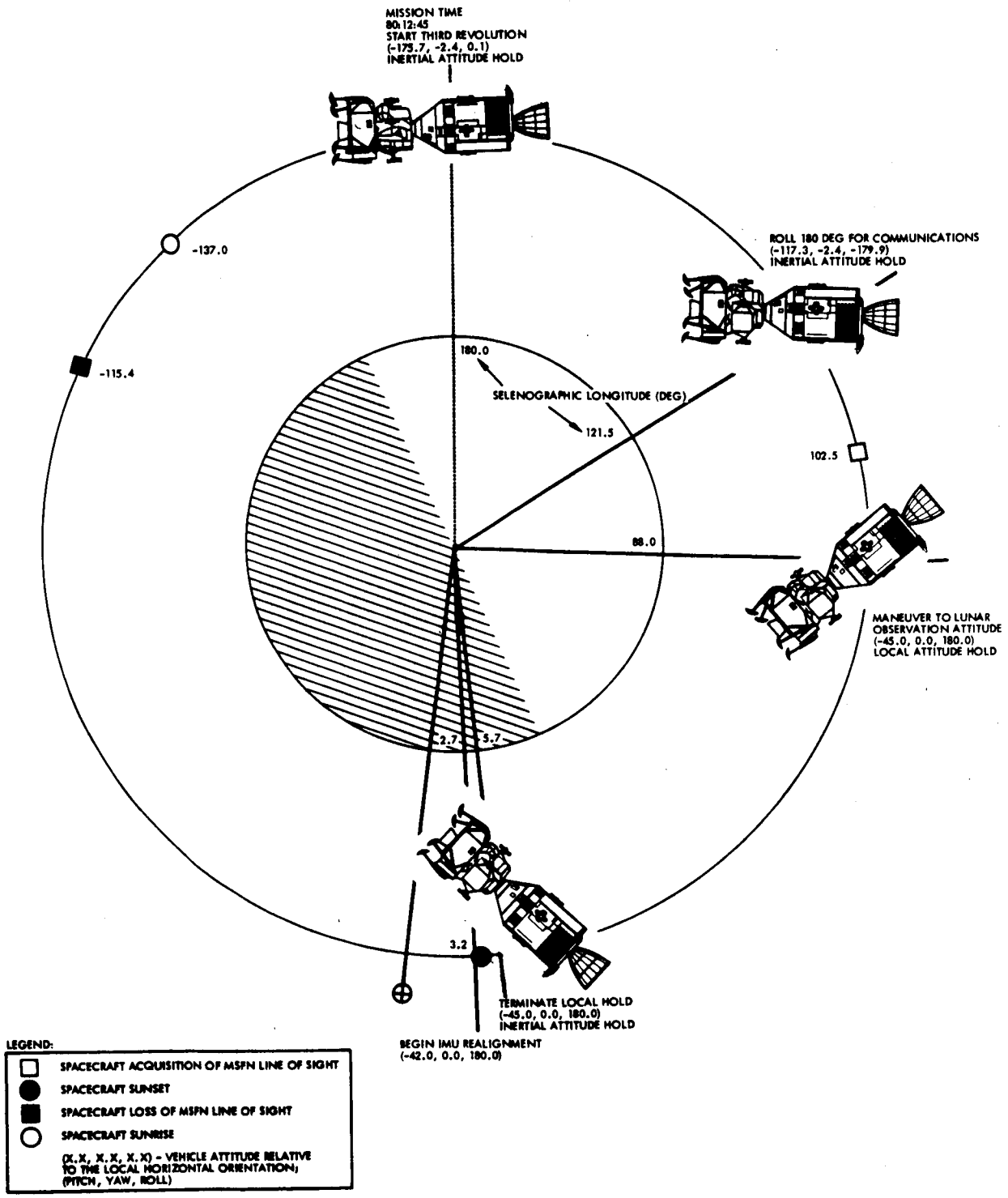

Figure 4. Third Revolution Major Events and Attitudes

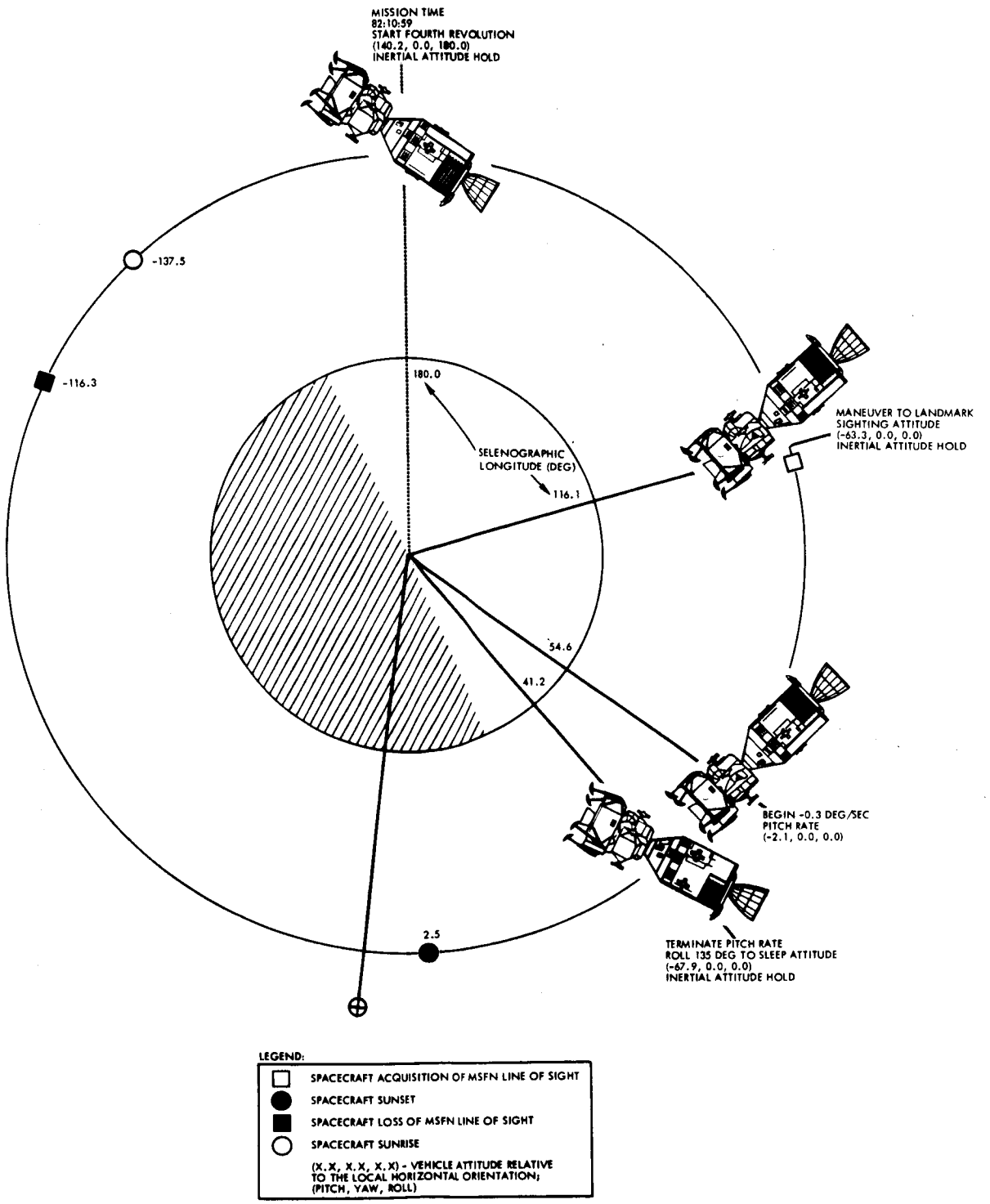

Figure 5. Fourth Revolution Major Events and Attitudes

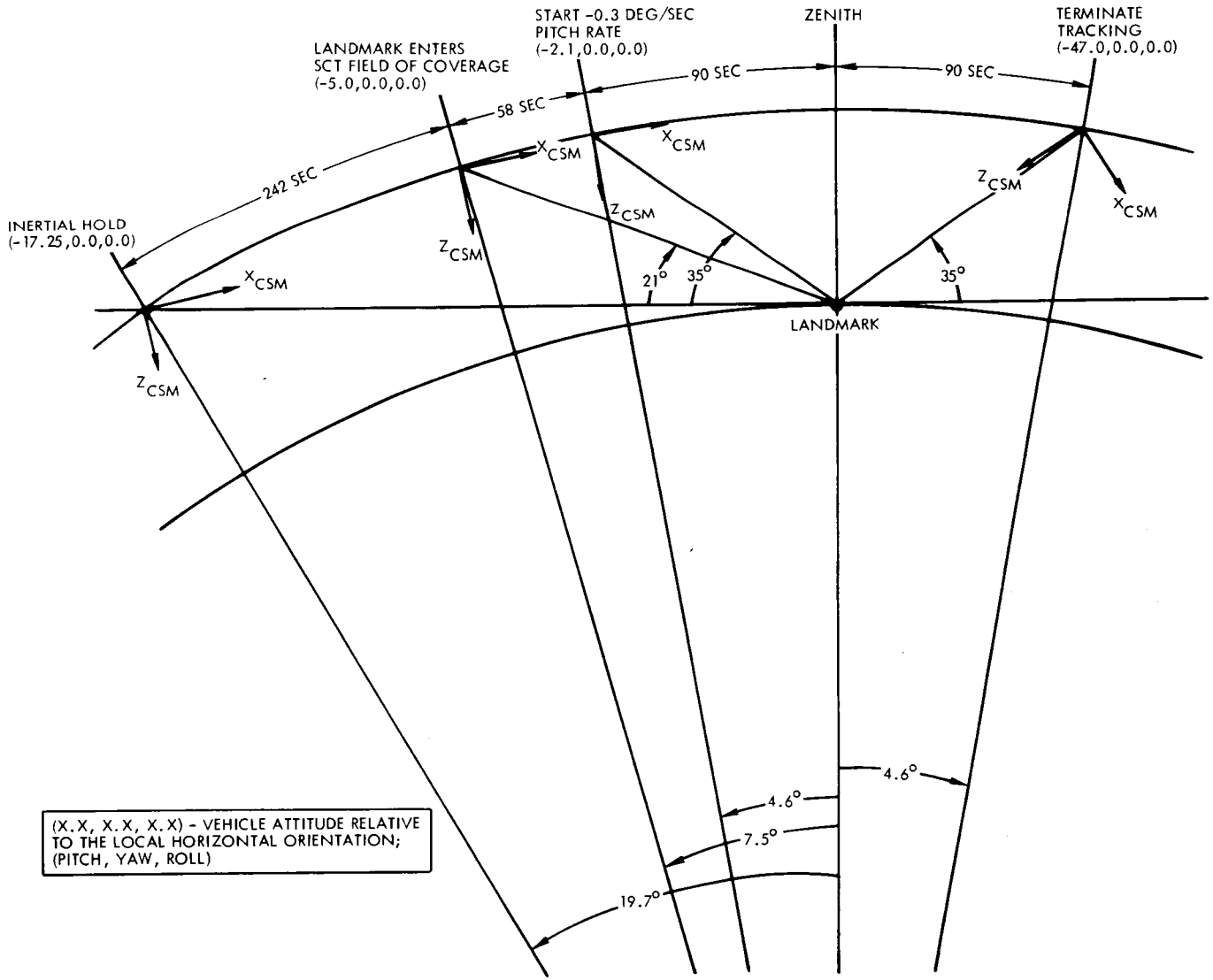

Figure 6. Tracking Geometry for Mode I Landmark Tracking

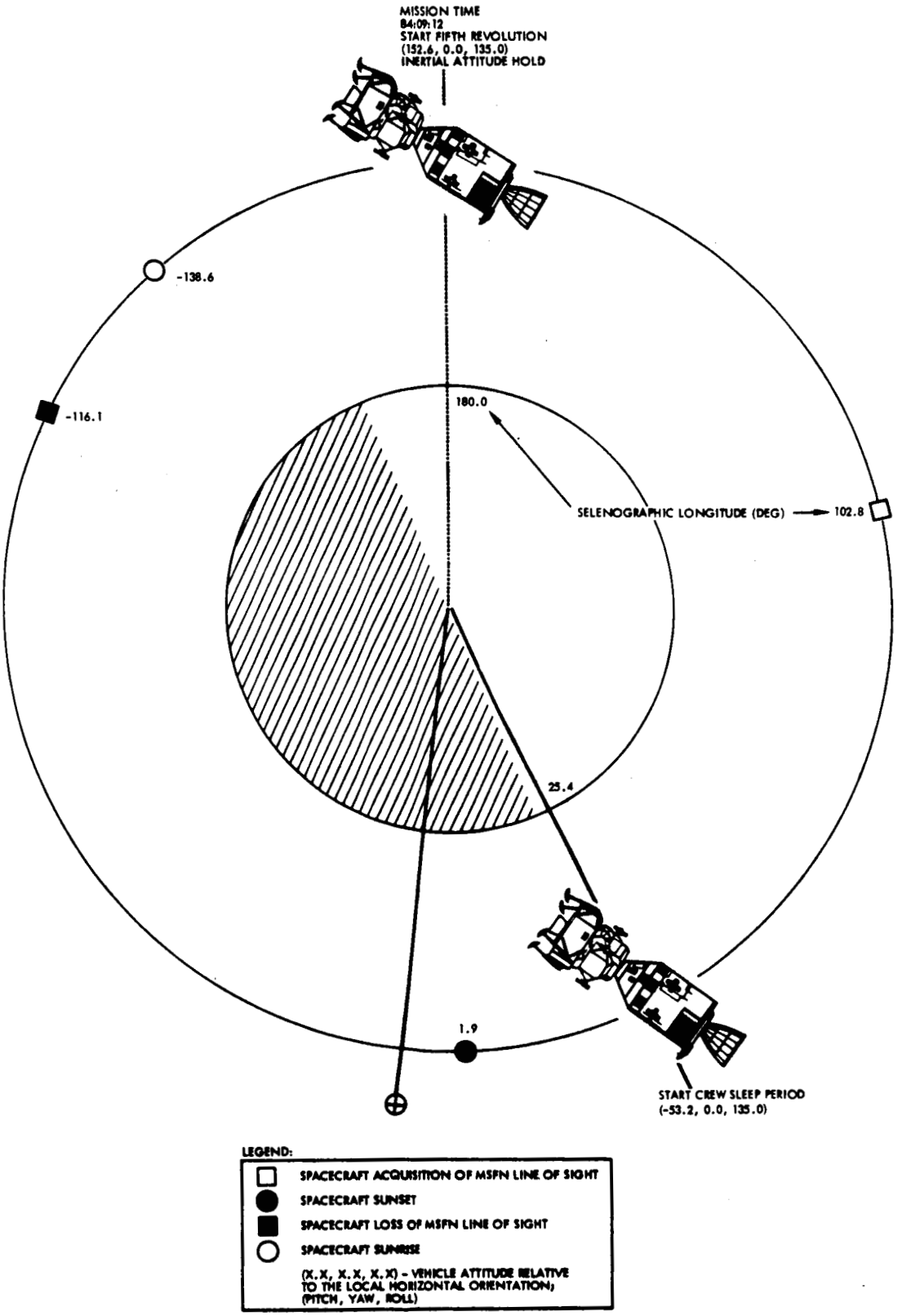

Figure 7. Fifth Revolution Major Events and Attitudes

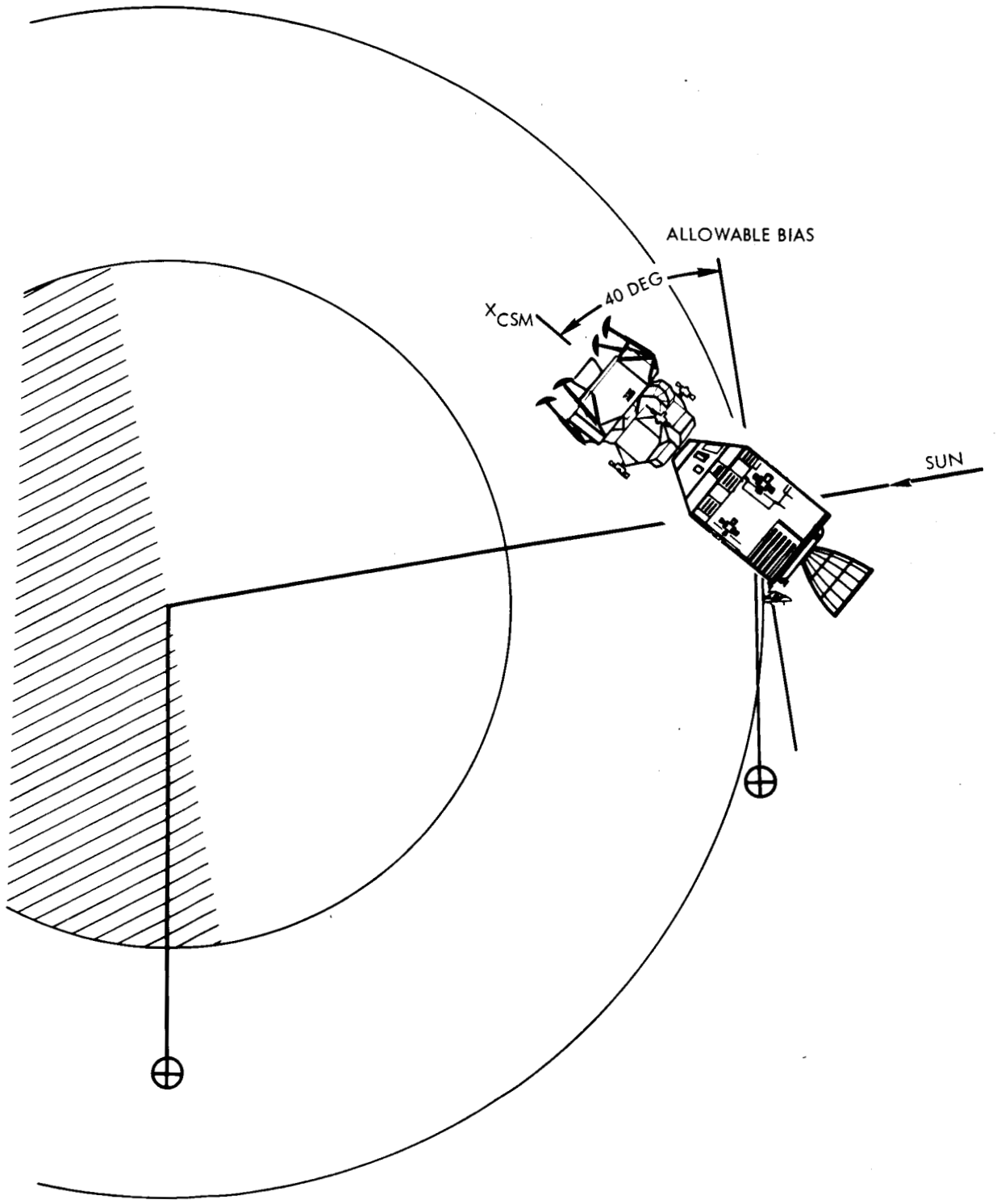

Figure 8. Lunar Orbit Sleep Geometry

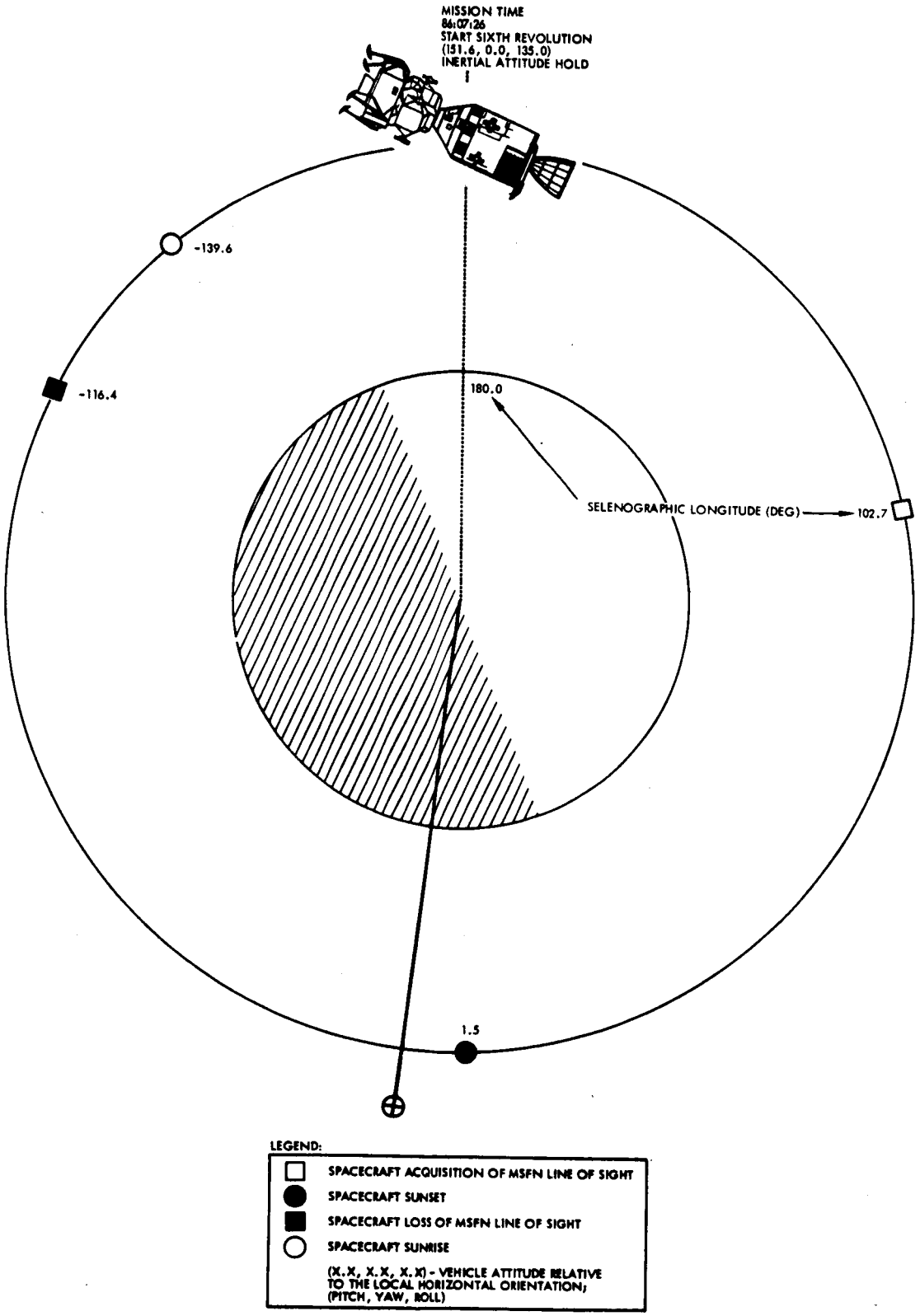

Figure 9. Sixth Revolution Major Events and Attitudes

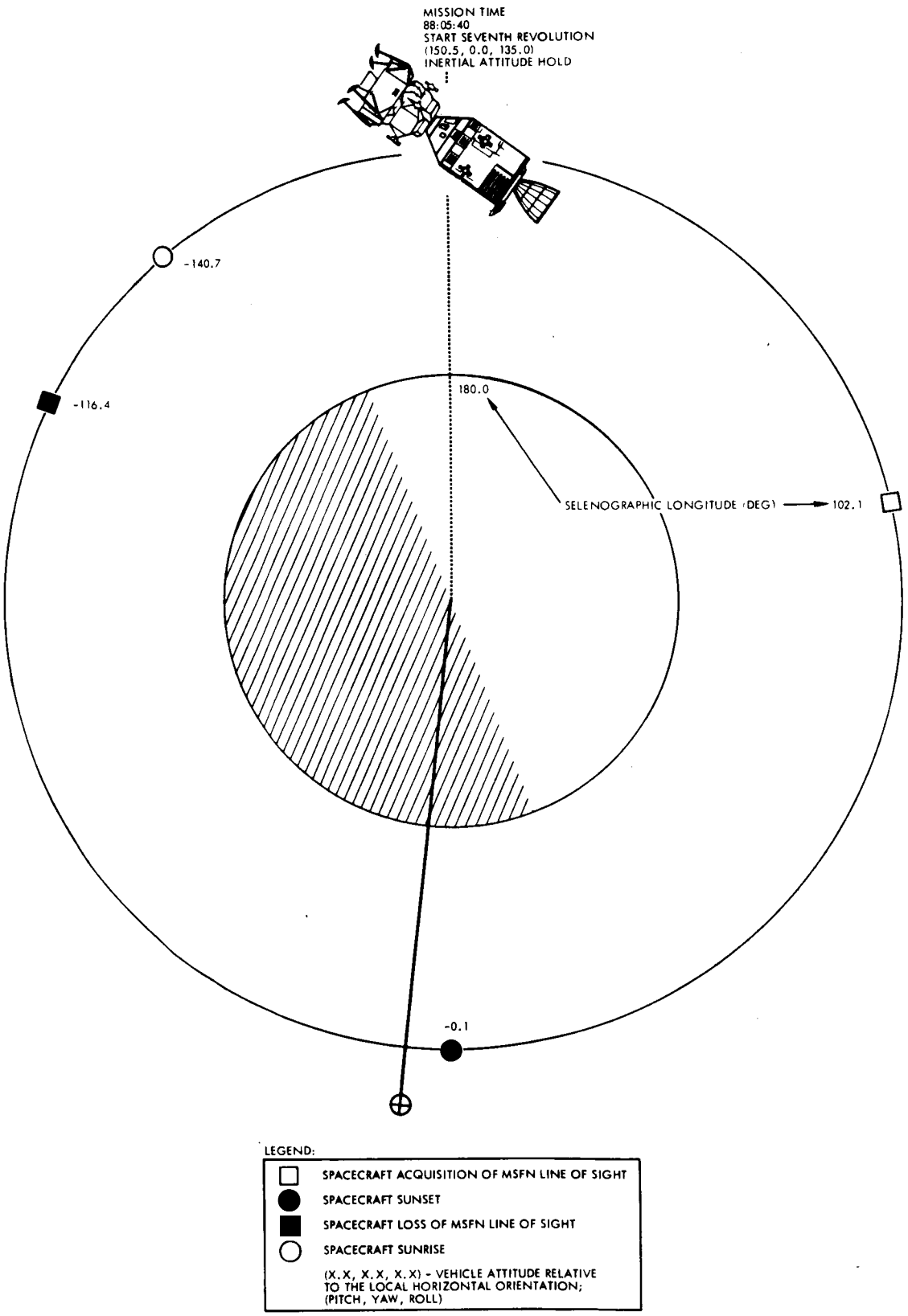

Figure 10. Seventh Revolution Major Events and Attitudes

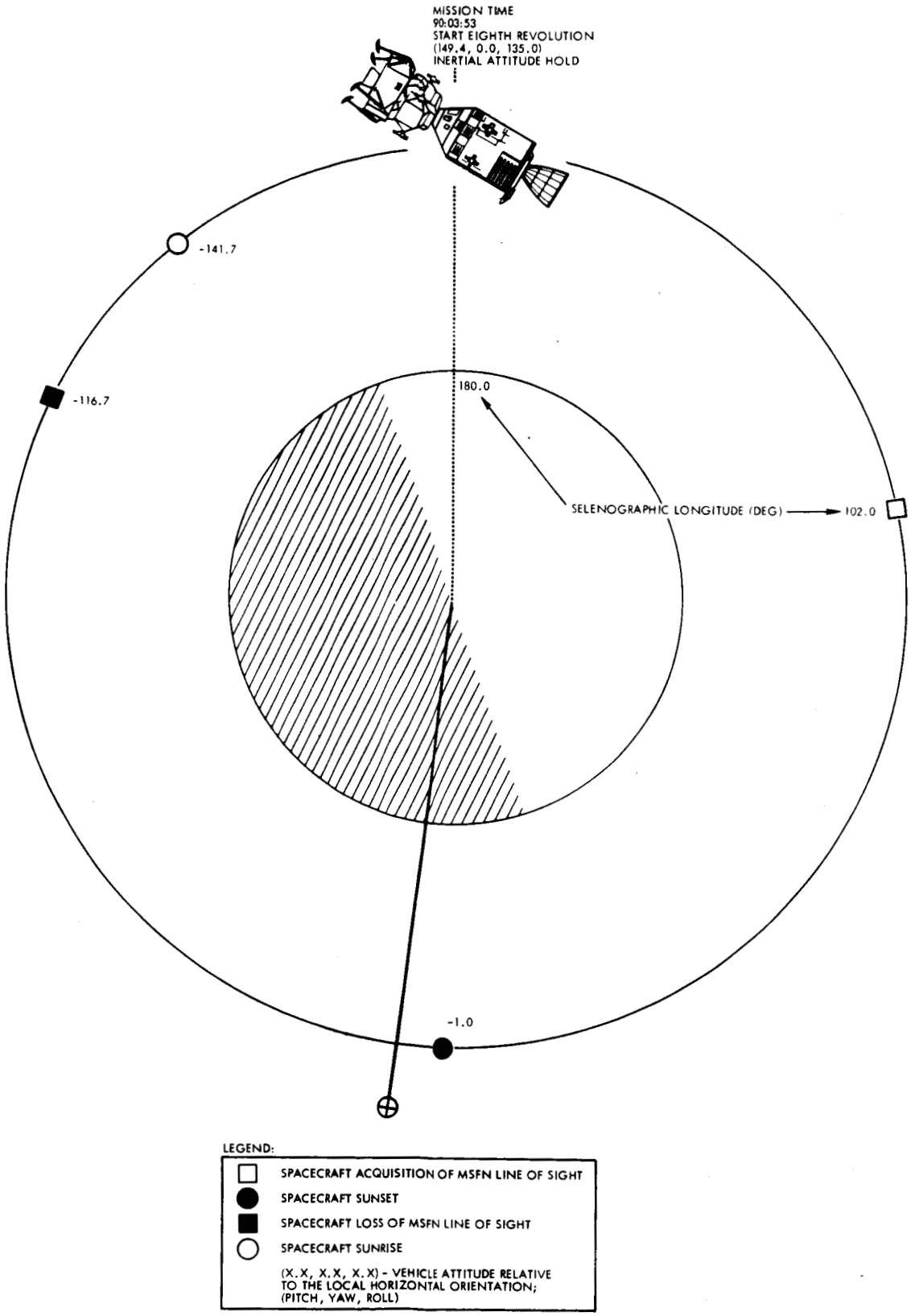

Figure 11. Eighth Revolution Major Events and Attitudes

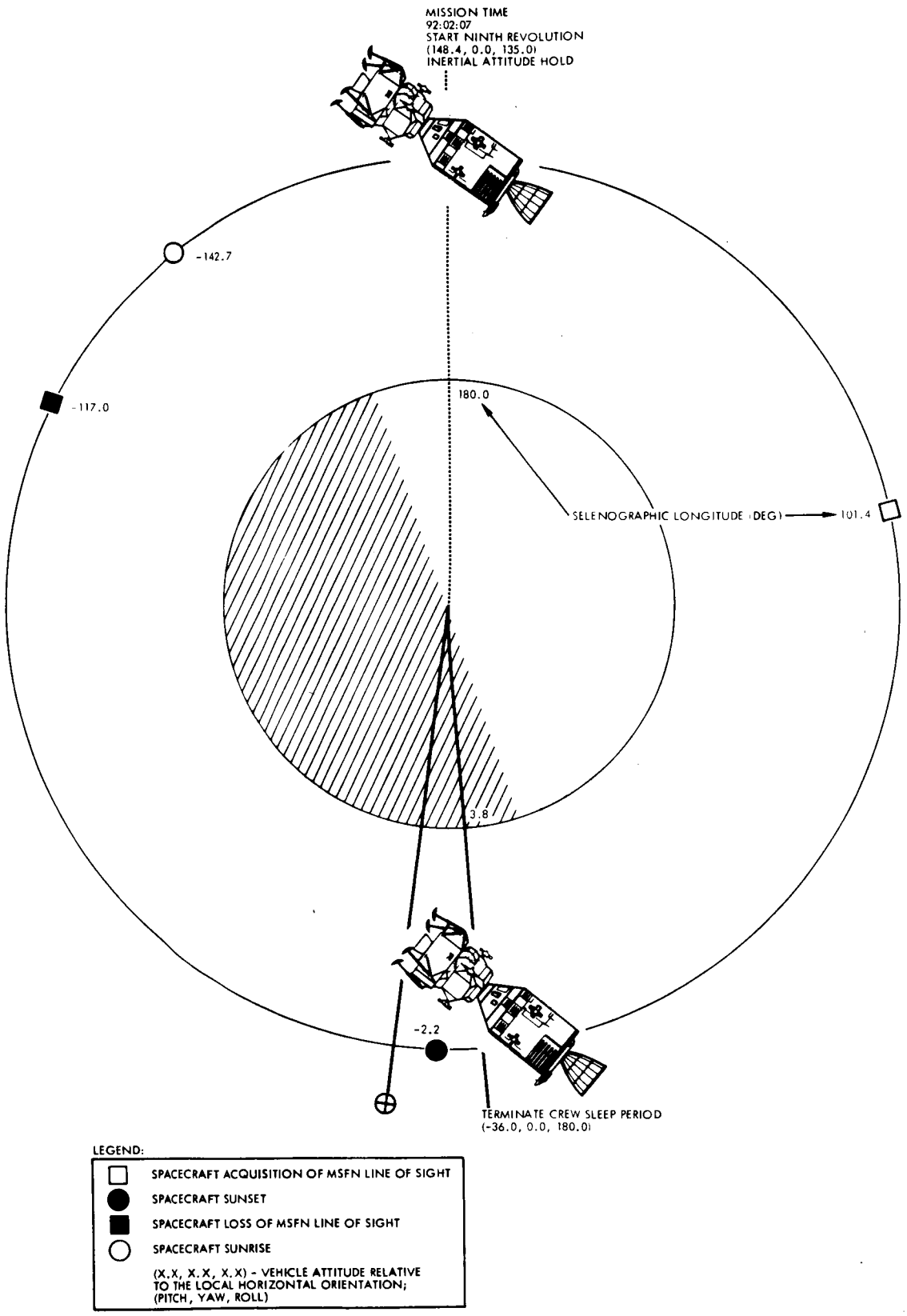

Figure 12. Ninth Revolution Major Events and Attitudes

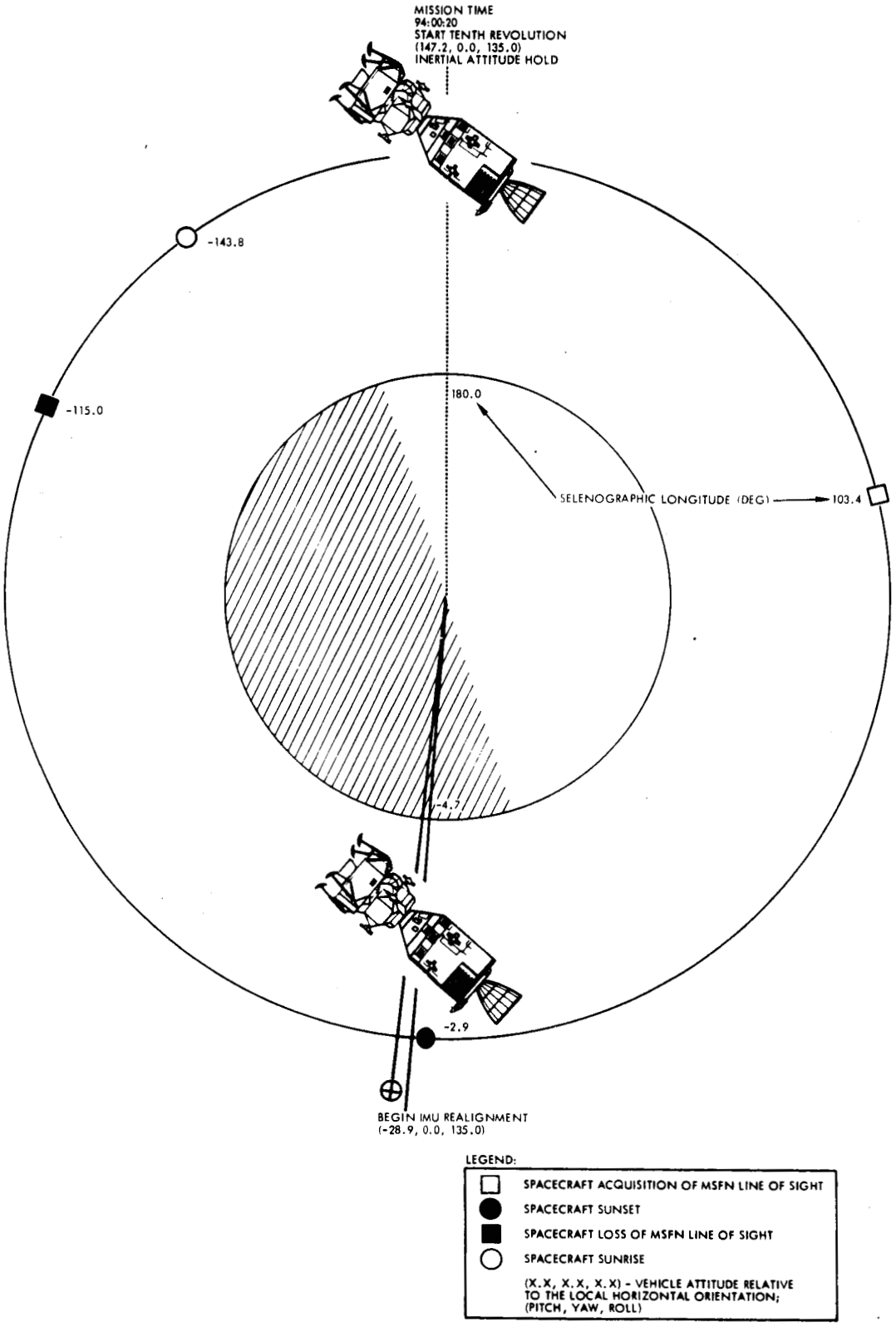

Figure 13. Tenth Revolution Major Events and Attitudes

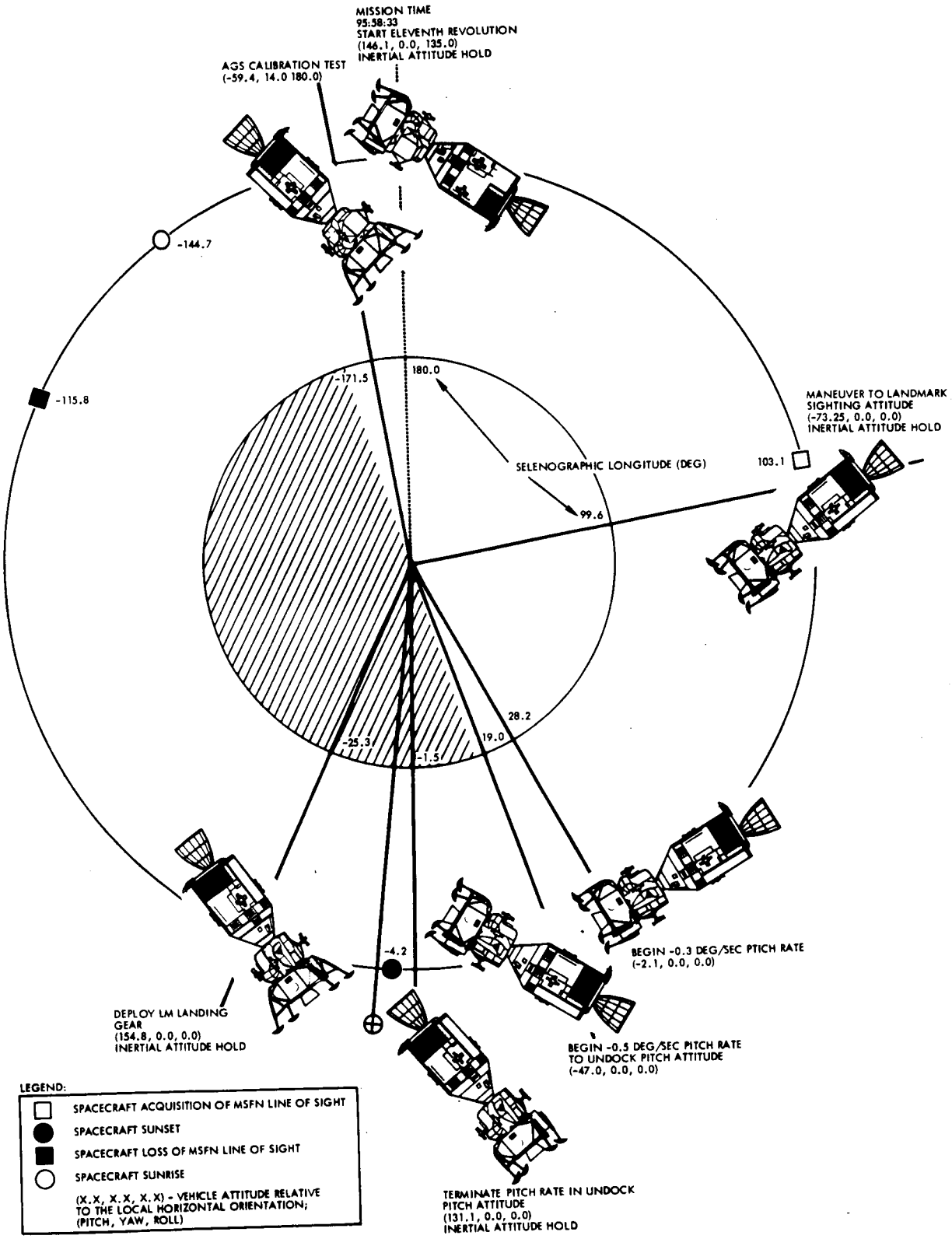

Figure 14. Eleventh Revolution Major Events and Attitudes

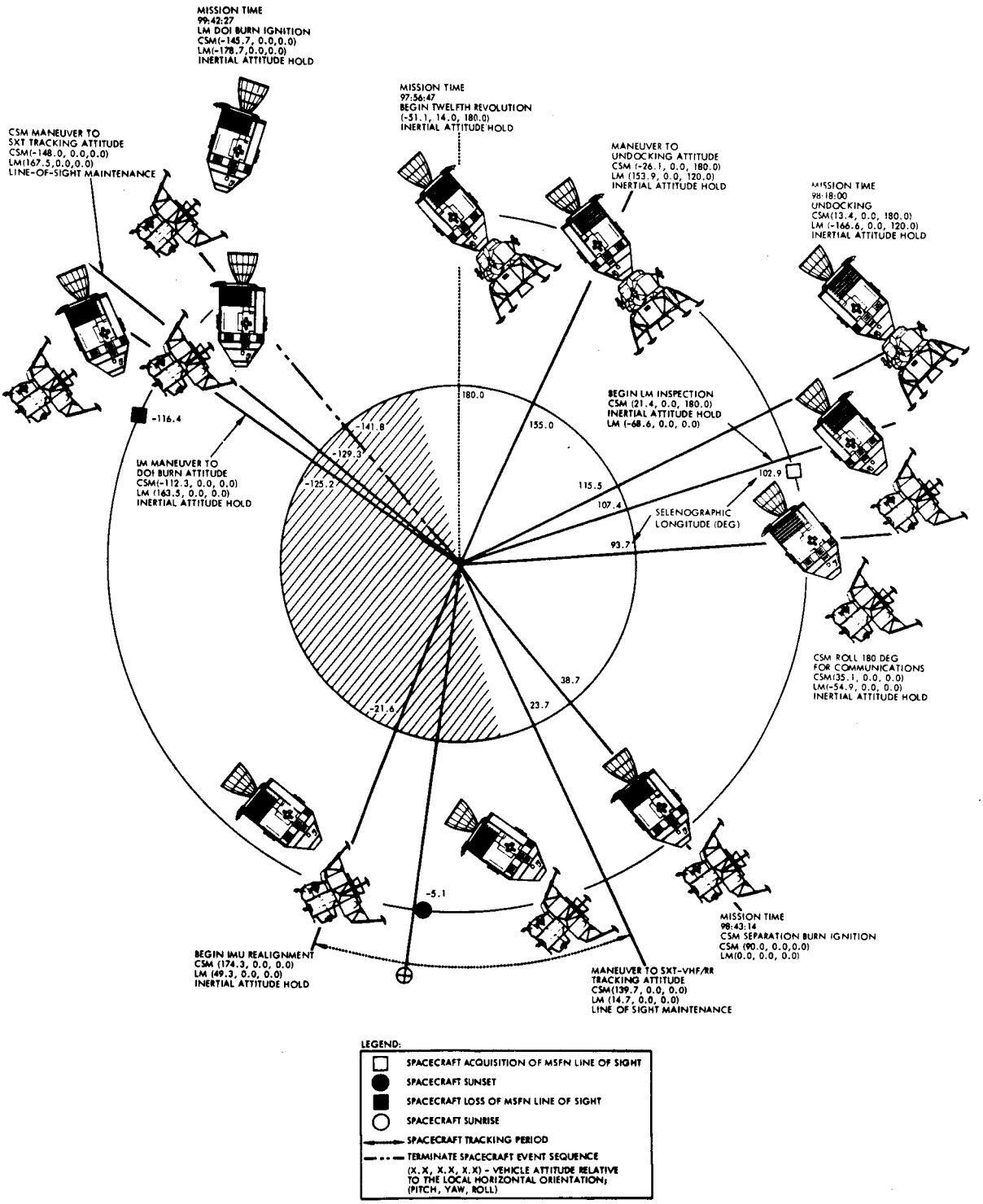

Figure 15. Twelfth Revolution until DOI Burn Ignition

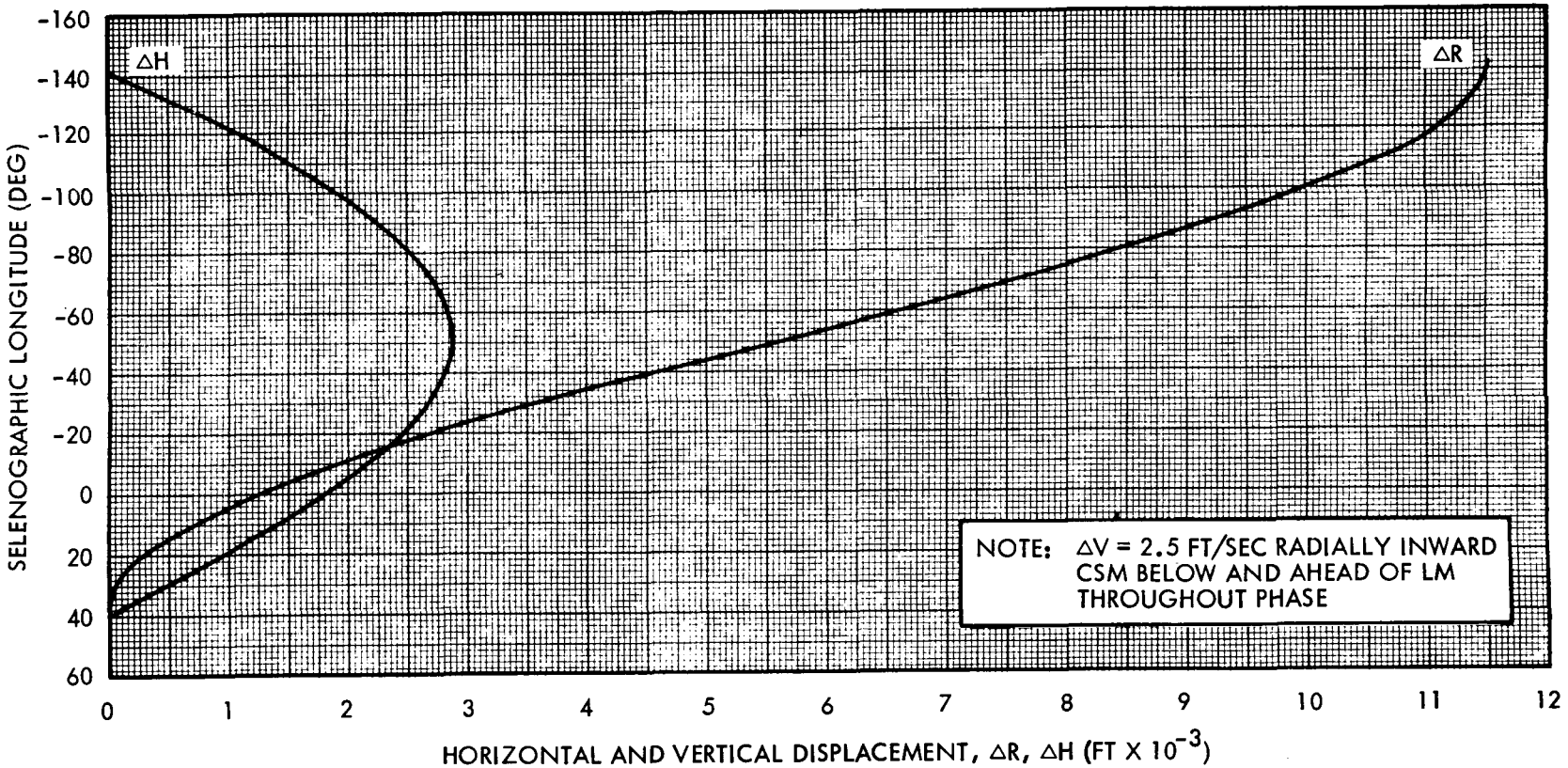

Figure 16. CSM/LM Relative Motion from Separation to DOI (LM Fixed)

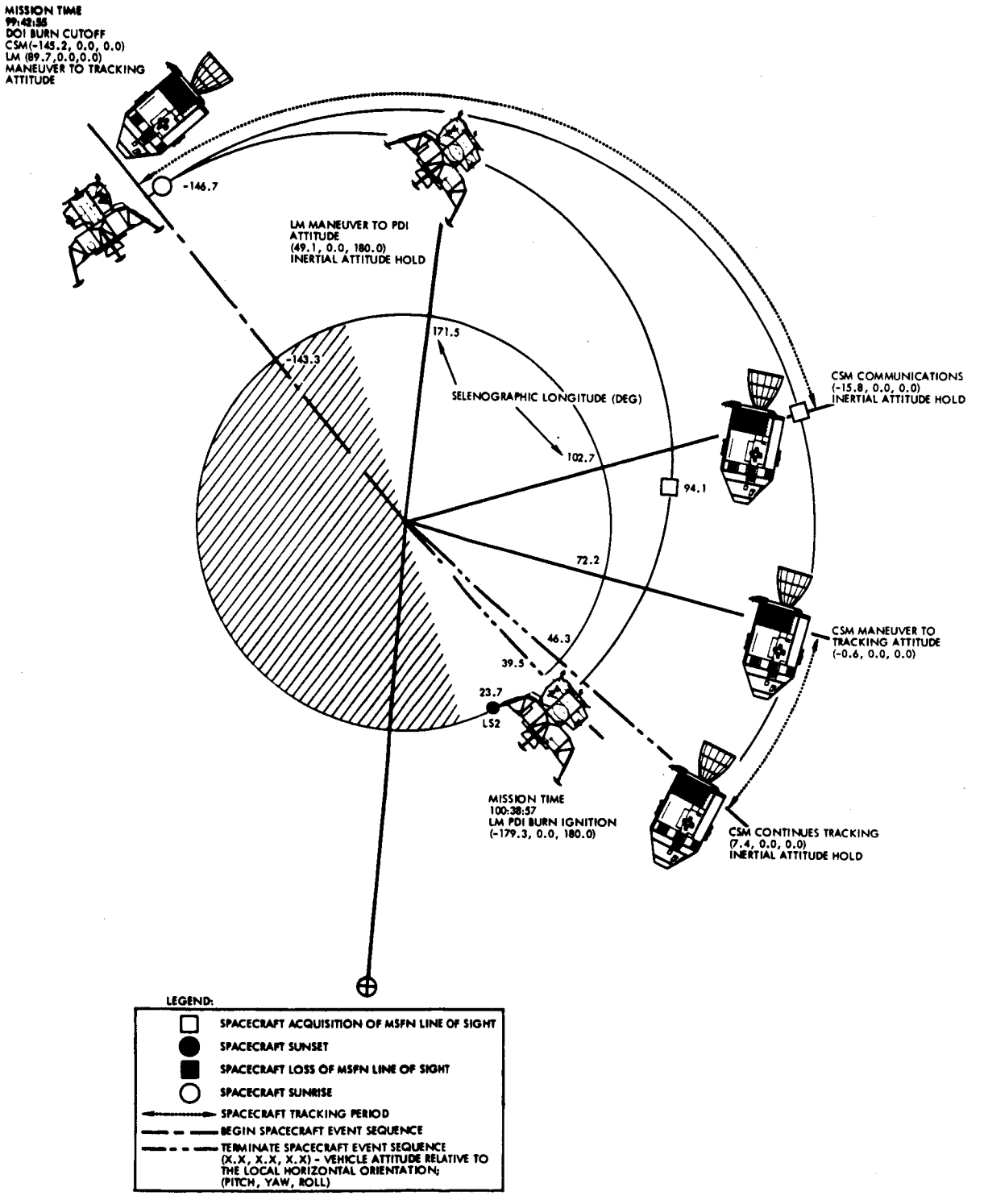

Figure 17. DOI Burn Cutoff to Powered Descent Initiation

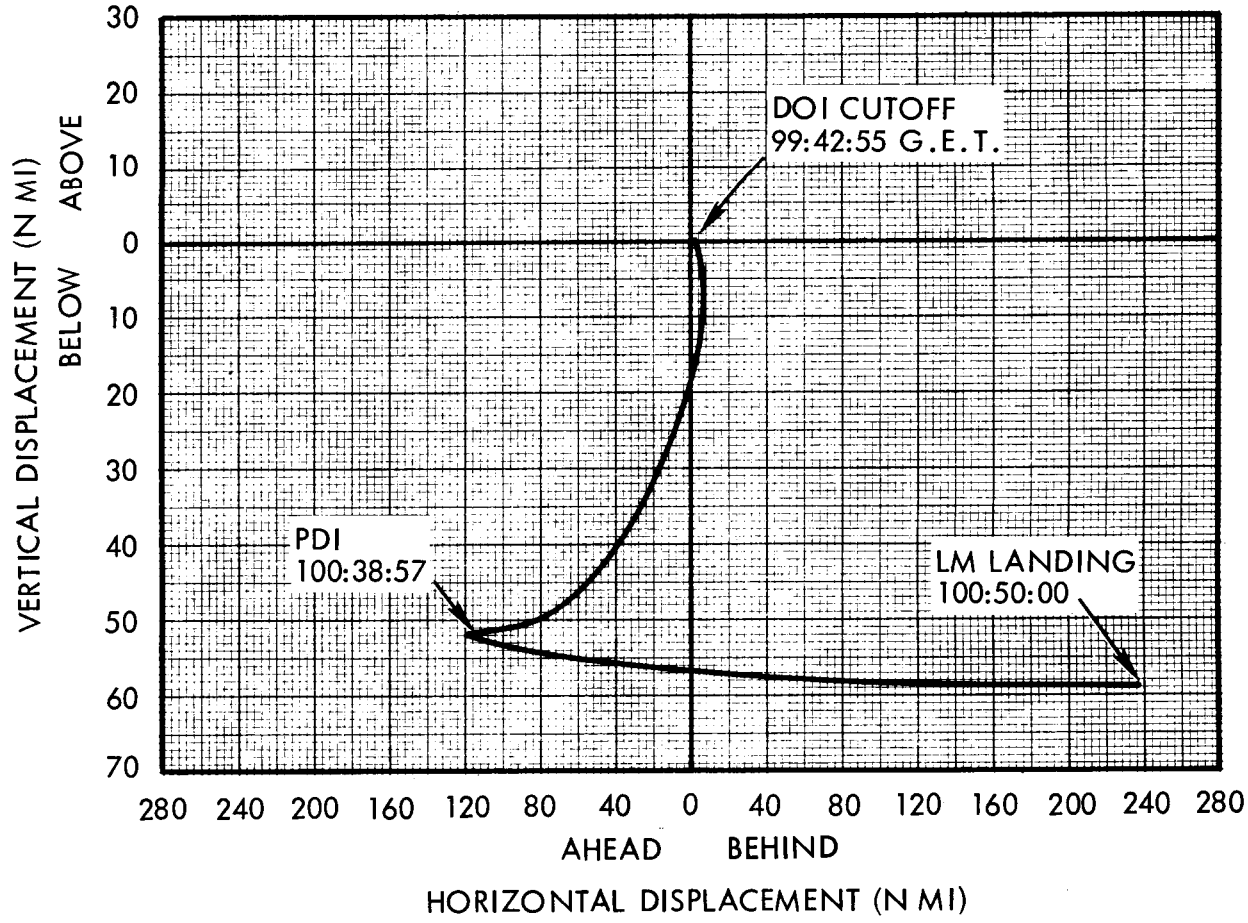

Figure 18. CSM/LM Relative Motion from DOI Burn Cutoff to LM Landing (CSM Fixed)

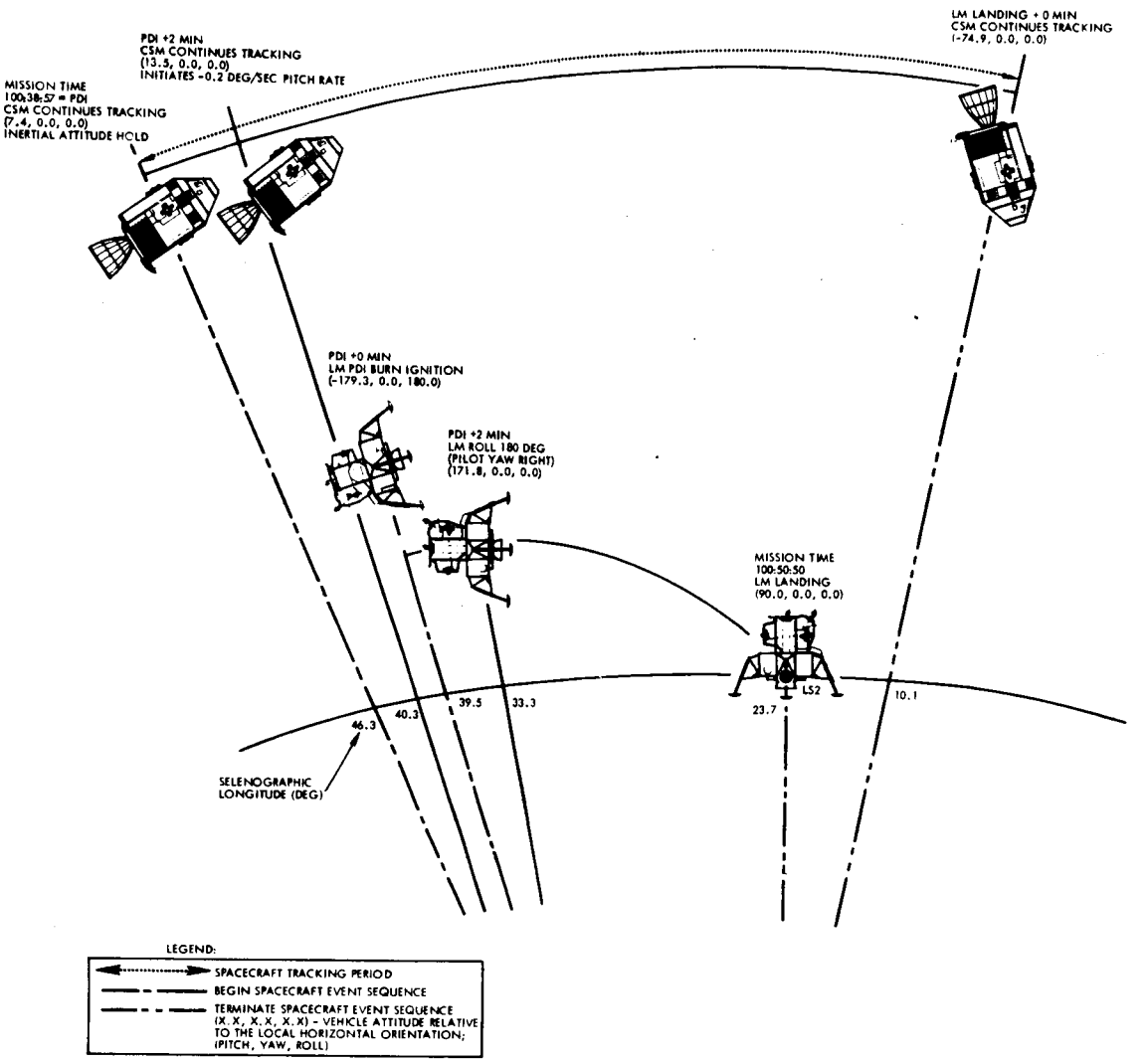

Figure 19. PDI Burn Ignition to LM Landing

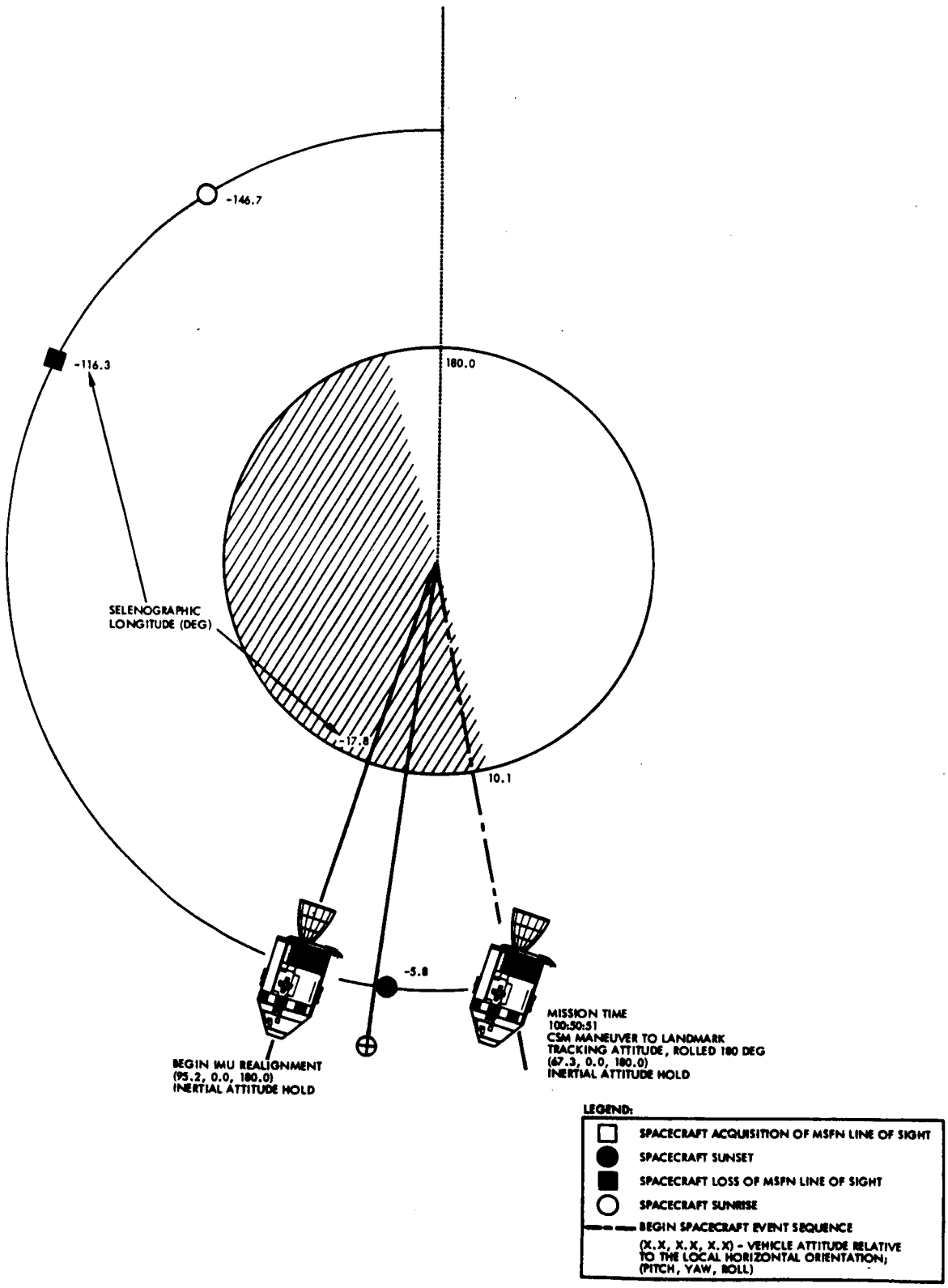

Figure 20. LM Landing to Initiation of Fourteenth Revolution

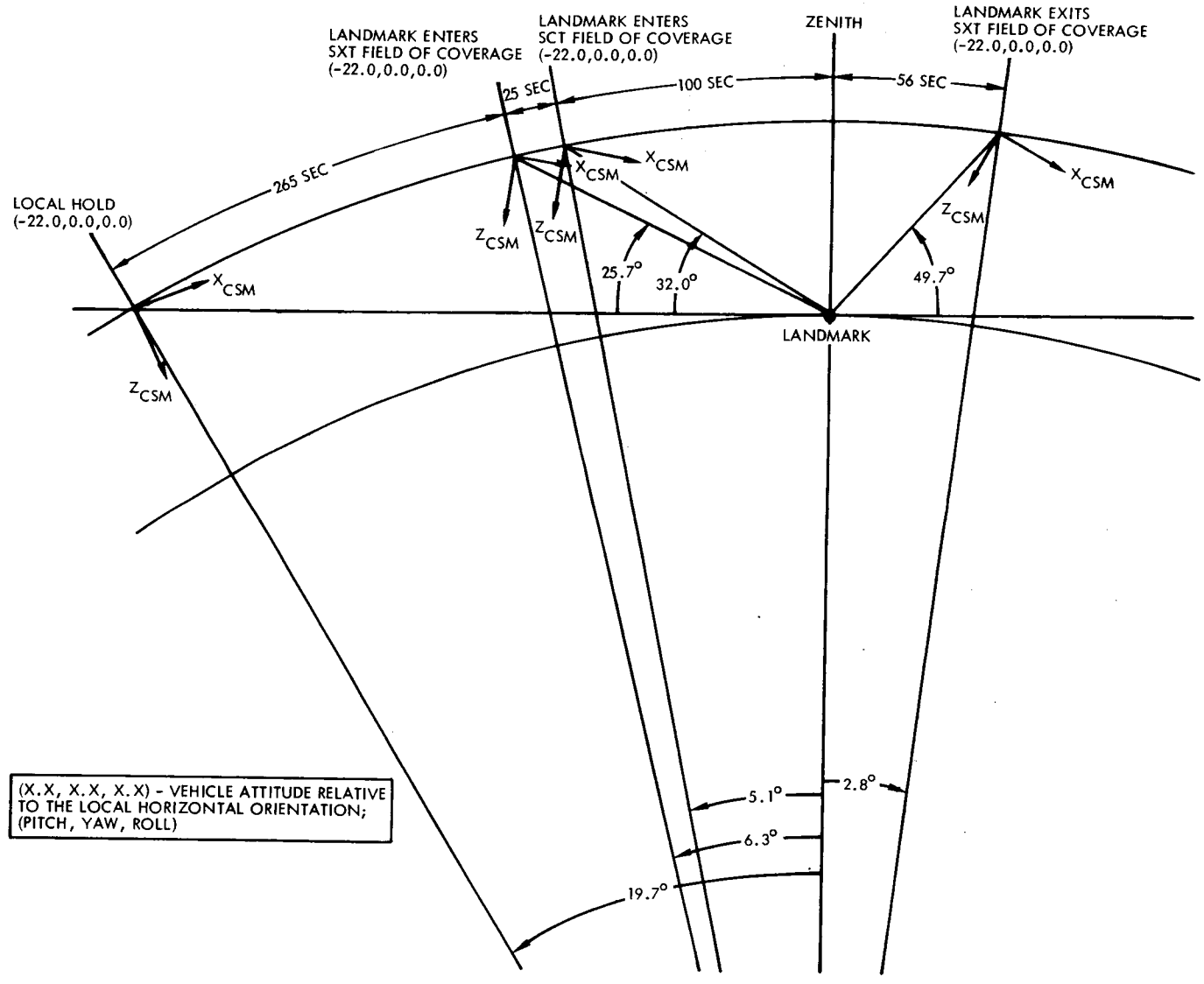

Figure 21. Tracking Geometry for Mode III Undocked Landmark Tracking

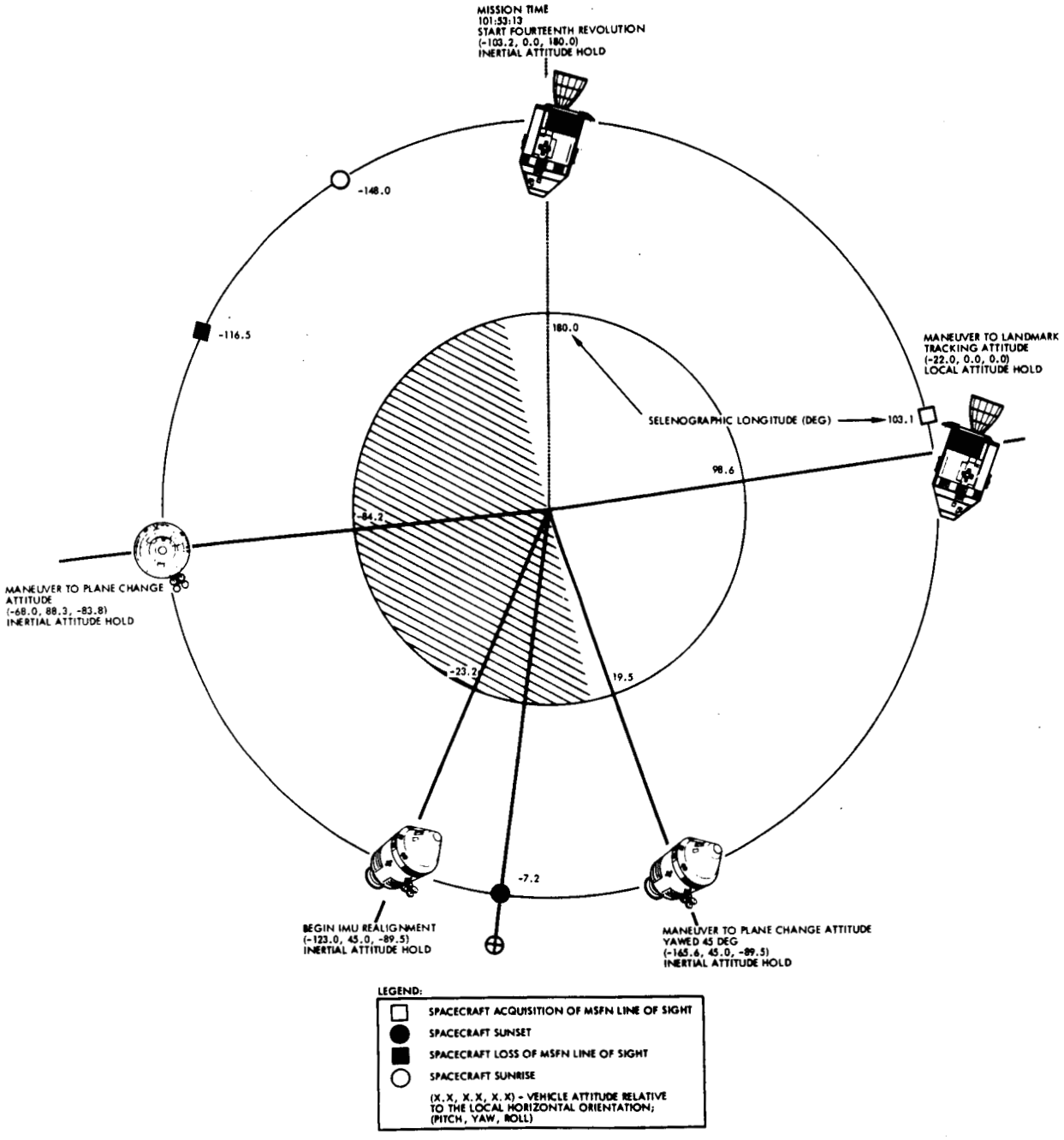

Figure 22. Fourteenth Revolution Major Events and Attitudes

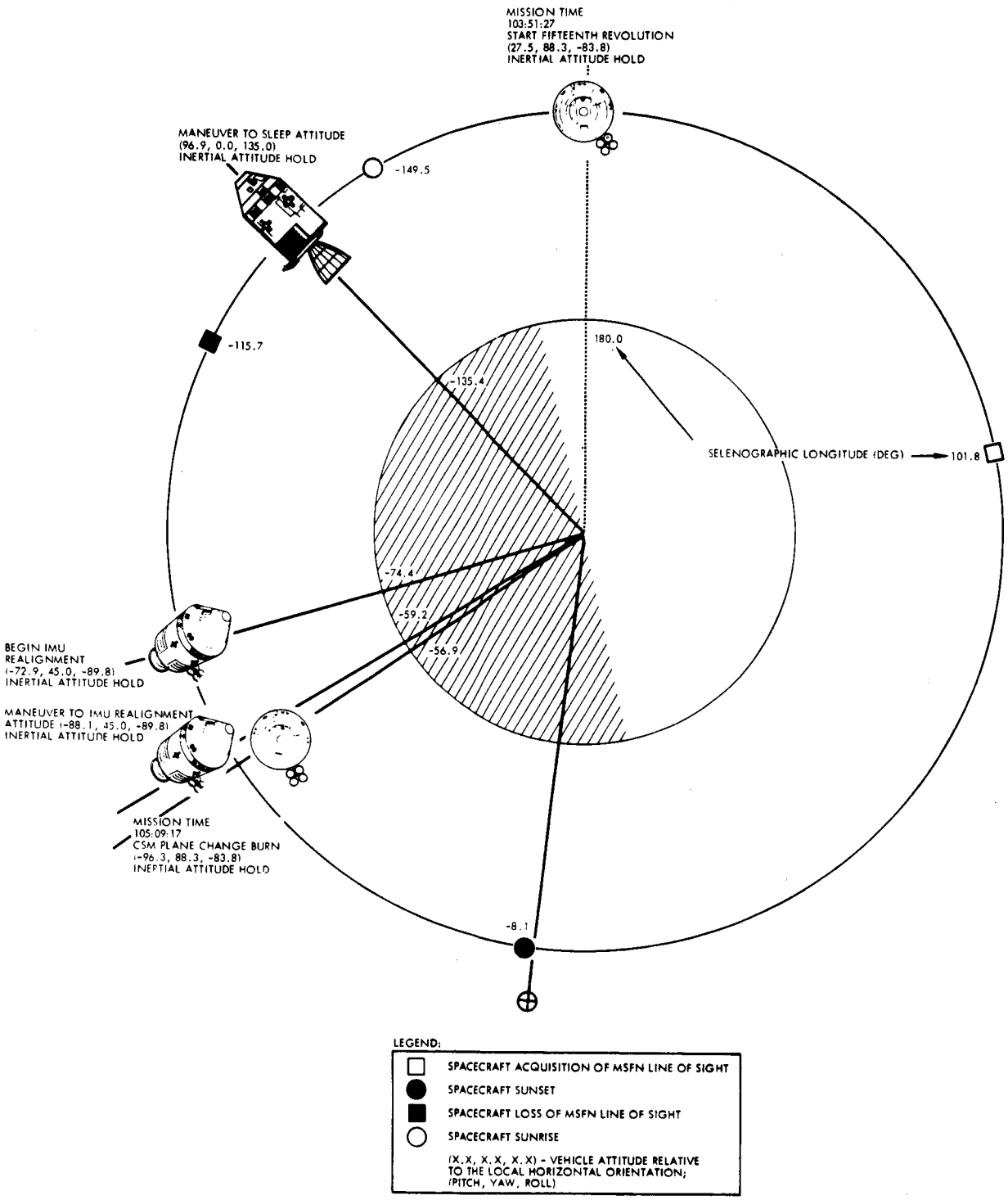

Figure 23. Fifteenth Revolution Major Events and Attitudes

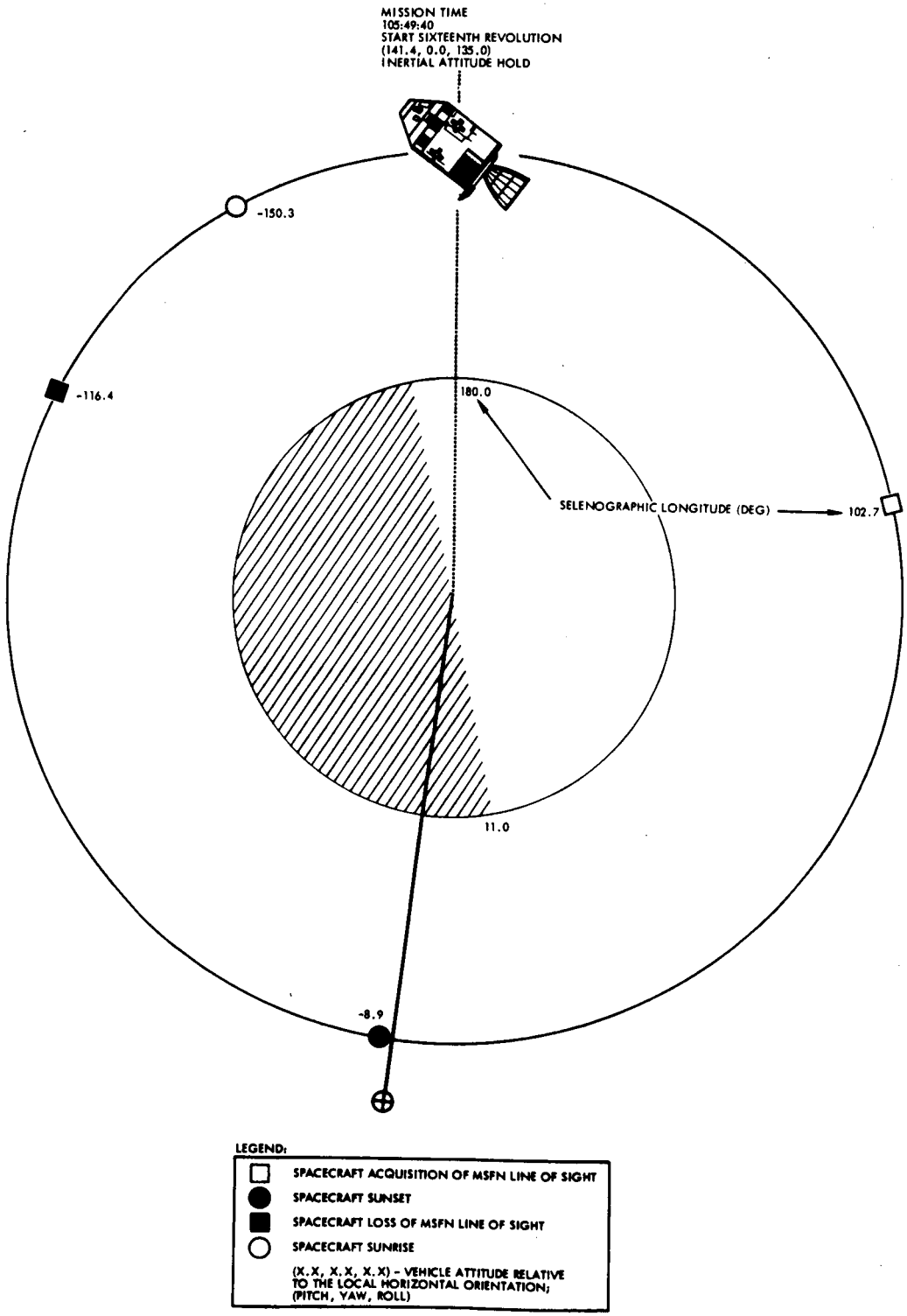

Figure 24. Sixteenth Revolution Major Events and Attitudes

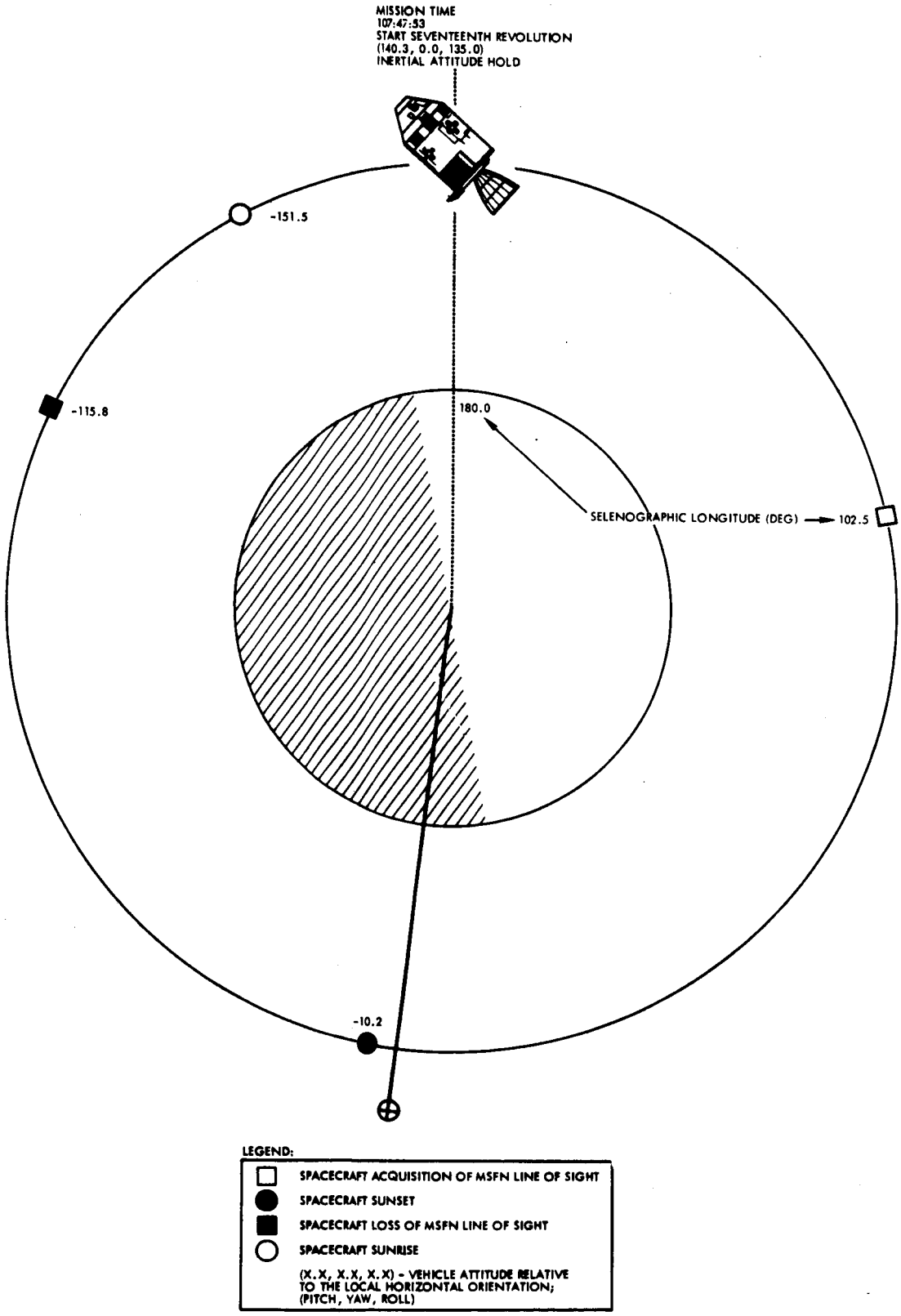

Figure 25. Seventeenth Revolution Major Events and Attitudes

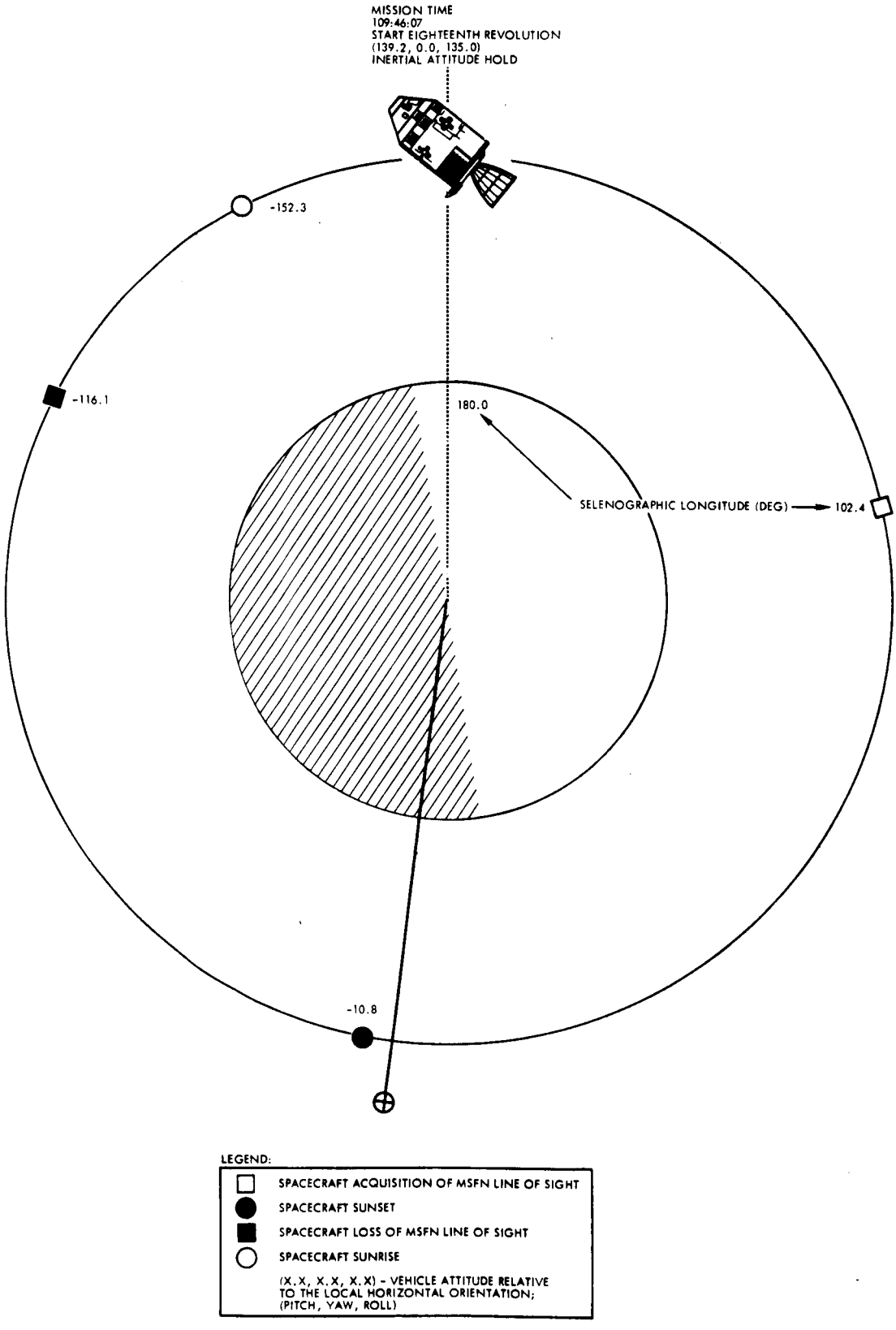

Figure 26. Eighteenth Revolution Major Events and Attitudes

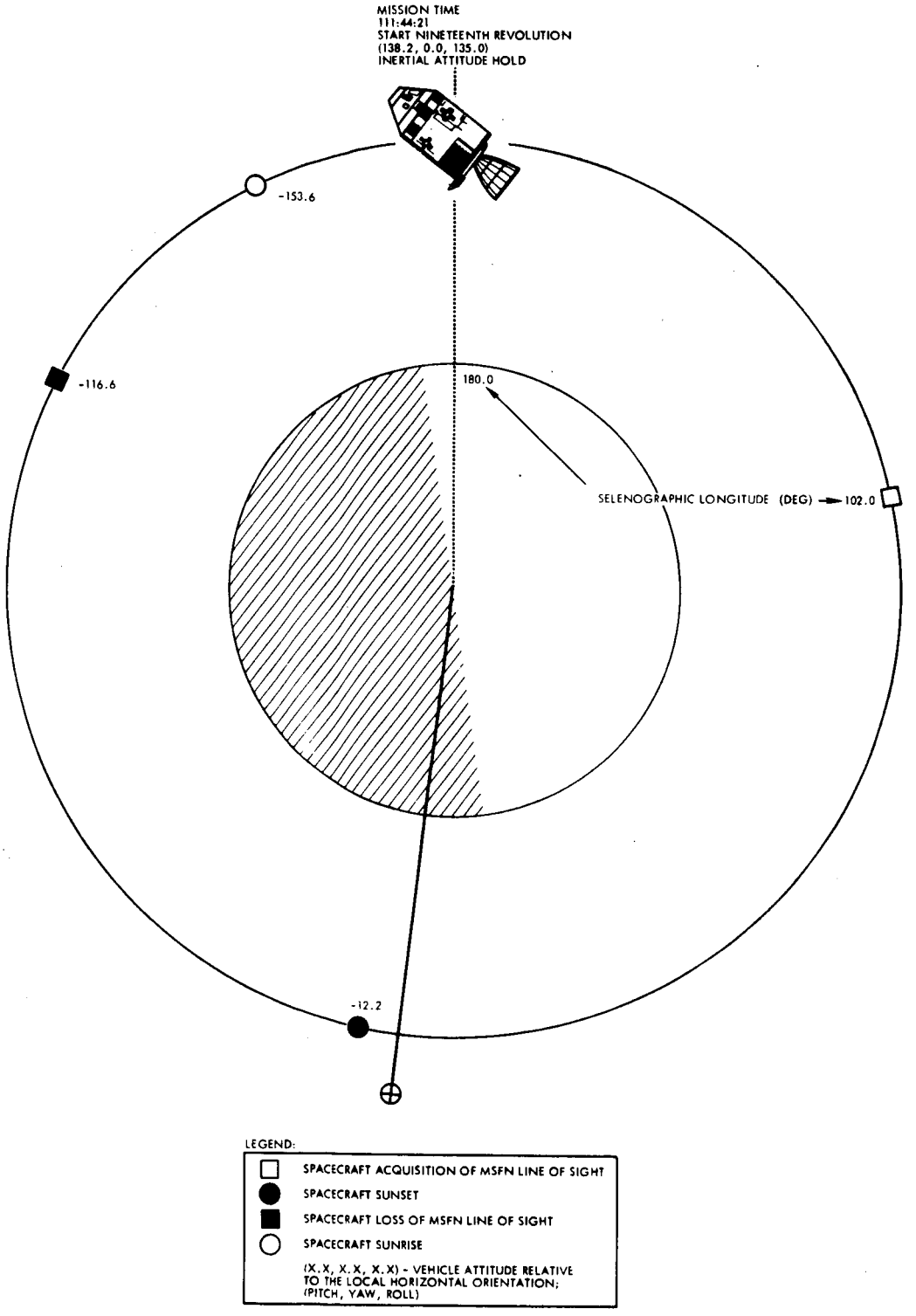

Figure 27. Nineteenth Revolution Major Events and Attitudes

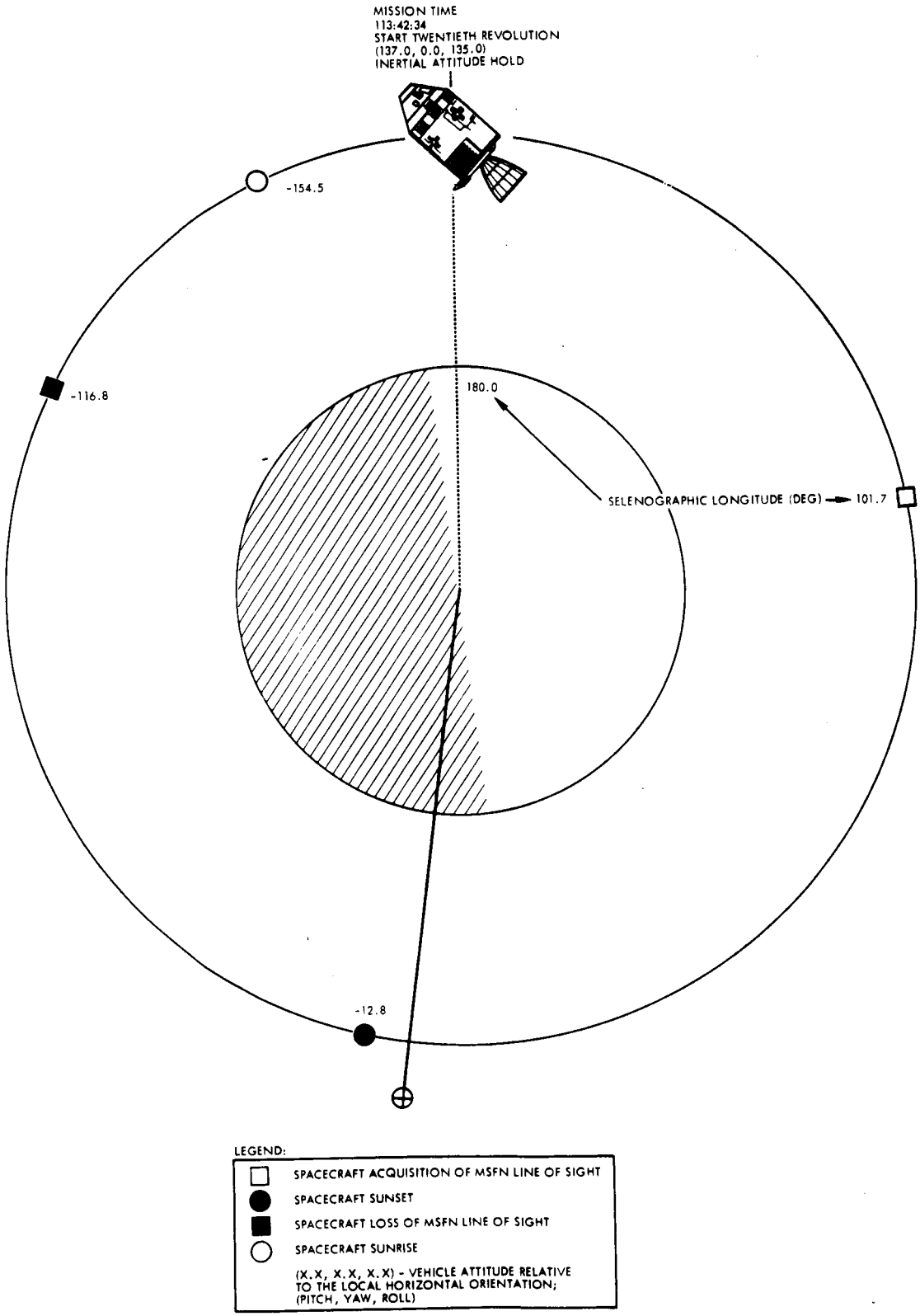

Figure 28. Twentieth Revolution Major Events and Attitudes

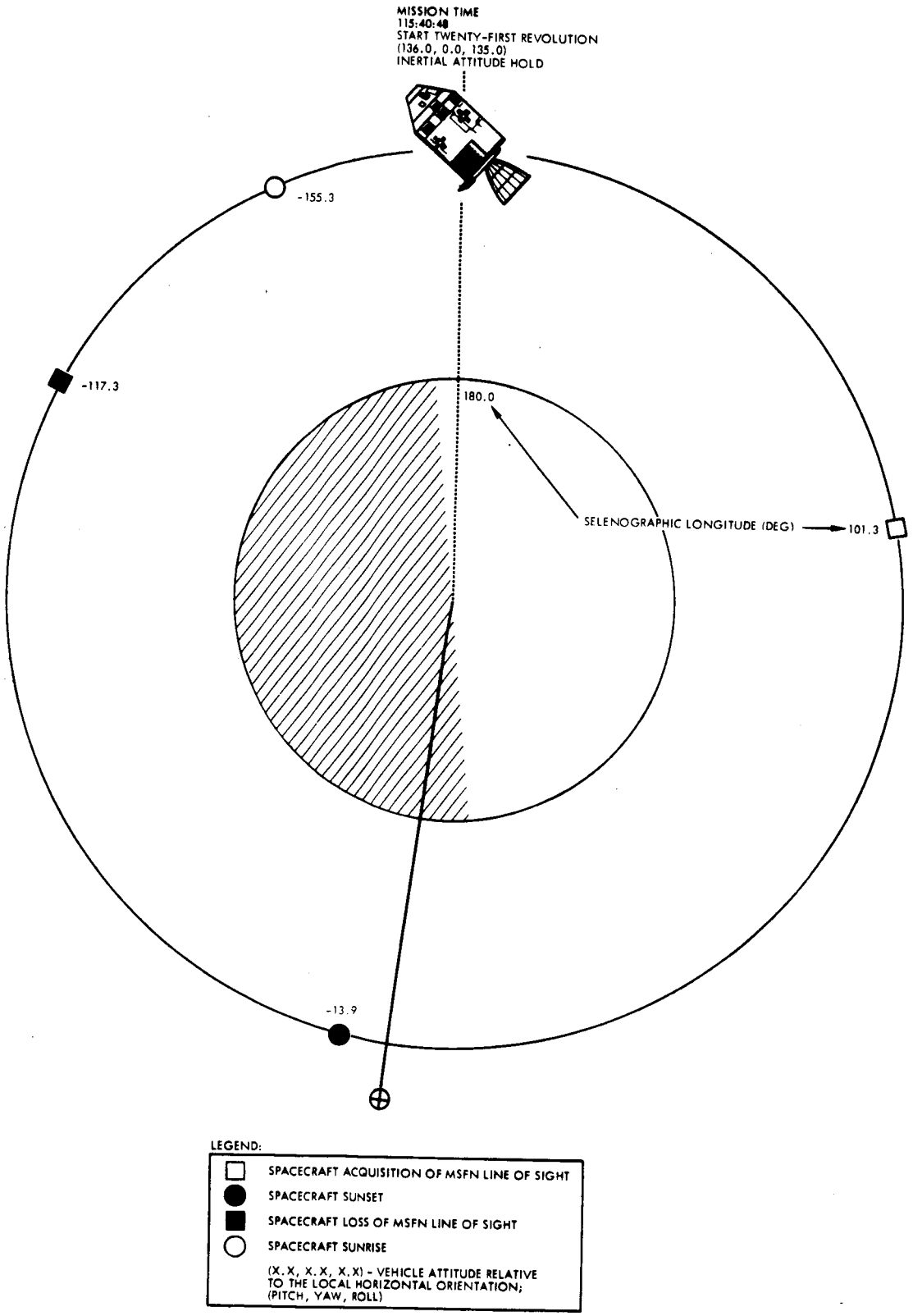

Figure 29. Twenty-first Revolution Major Events and Attitudes

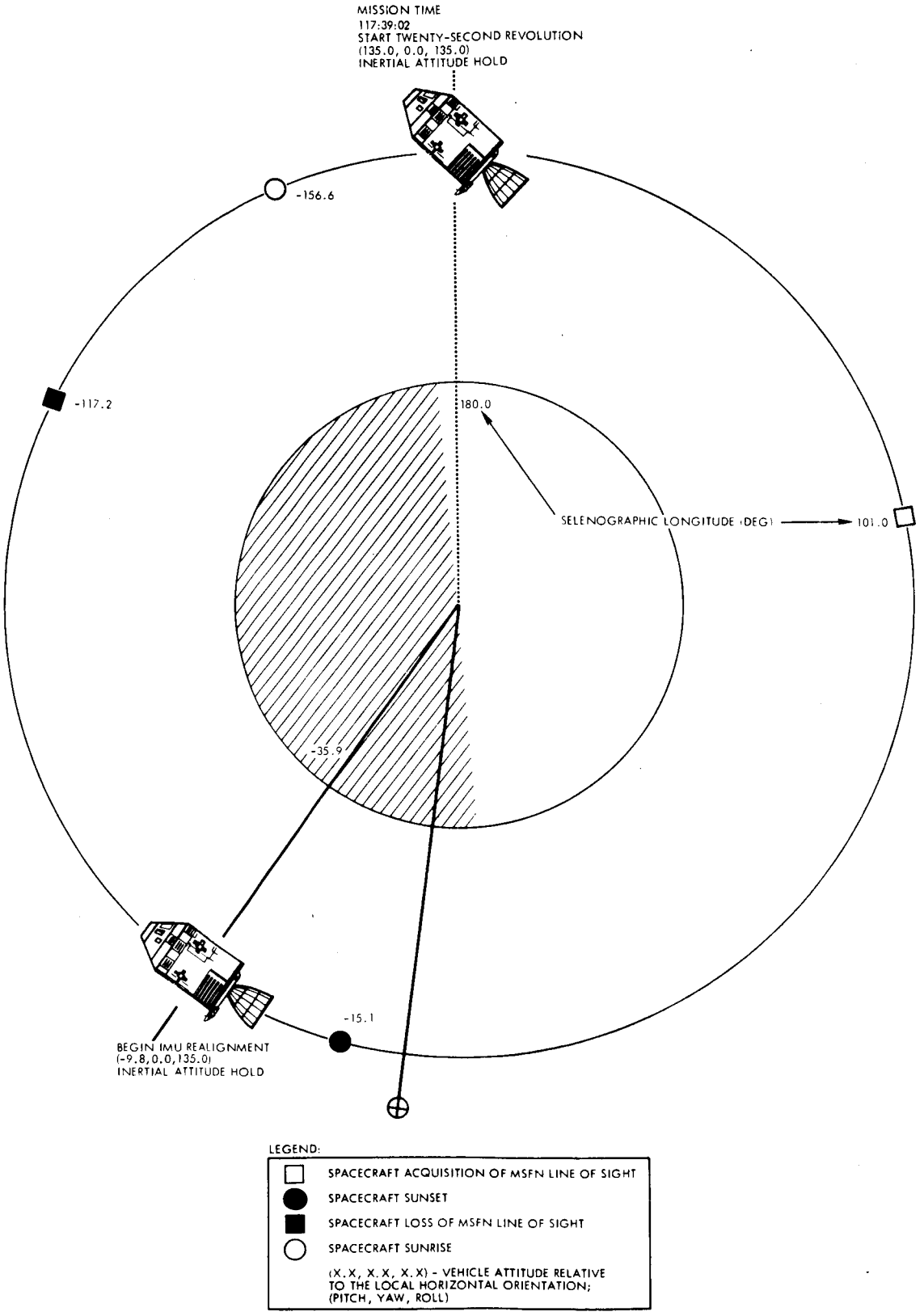

Figure 30. Twenty-second Revolution Major Events and Attitudes

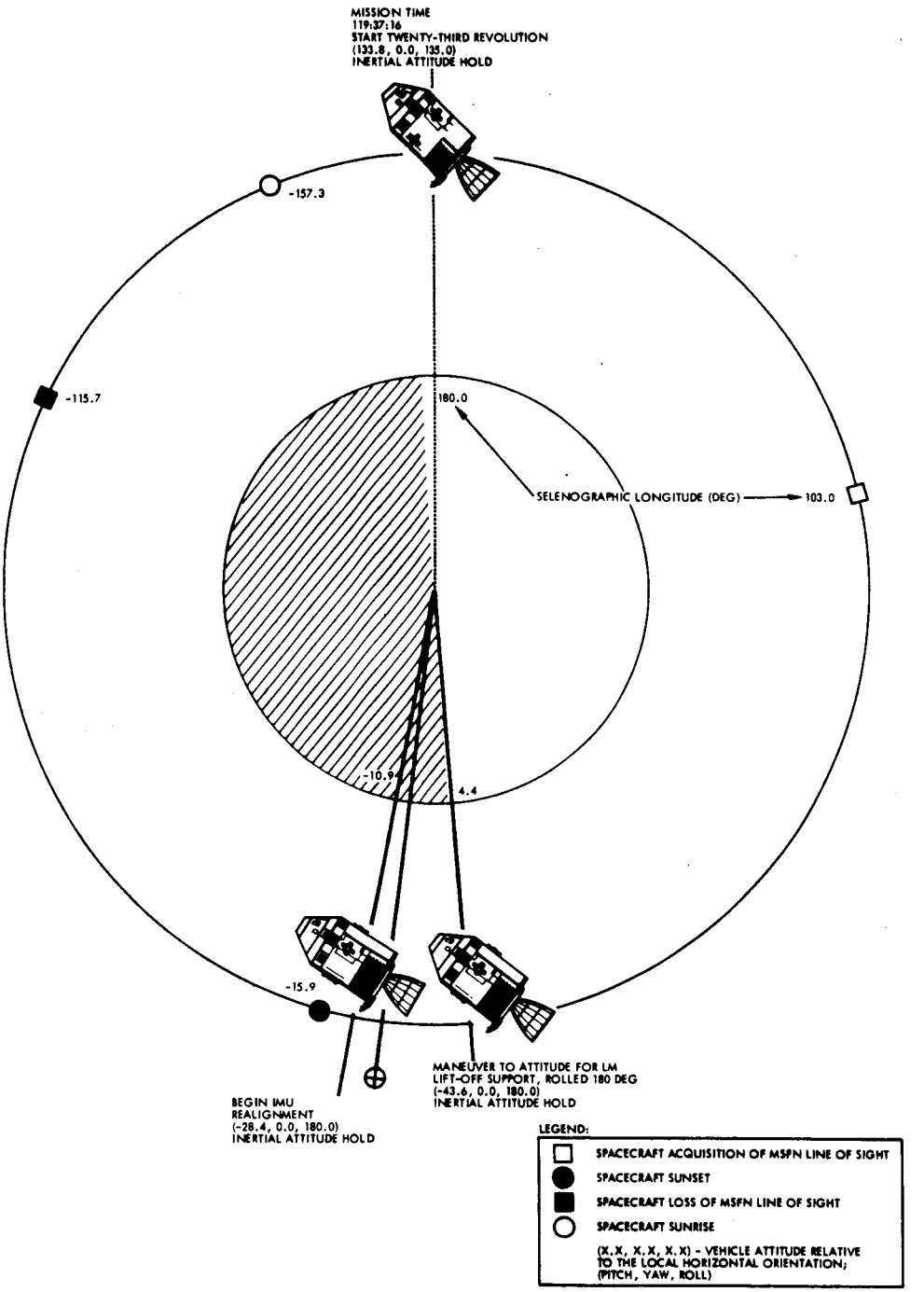

Figure 31. Twenty-third Revolution Major Events and Attitudes

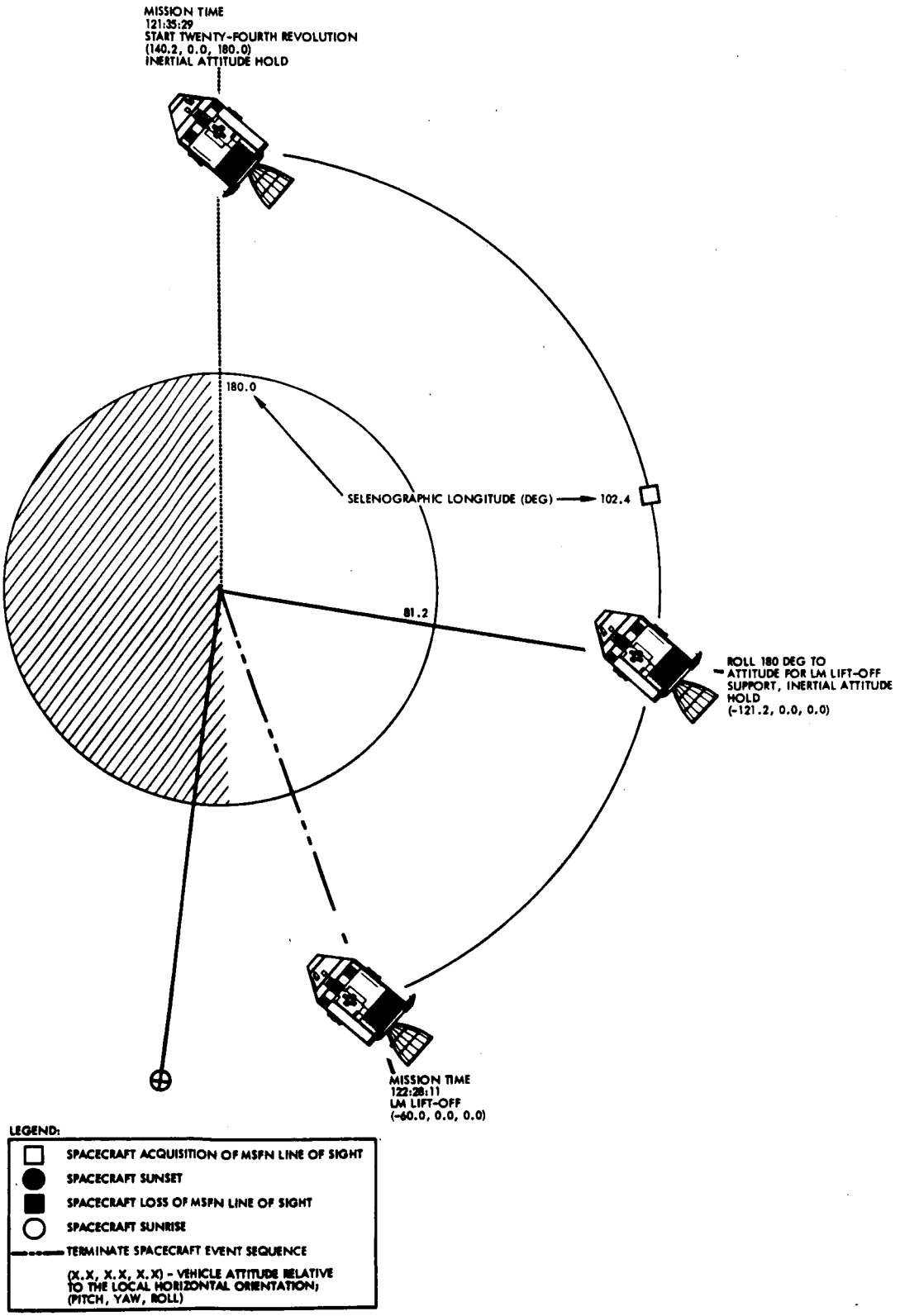

Figure 32. Twenty-fourth Revolution until LM Lift-off

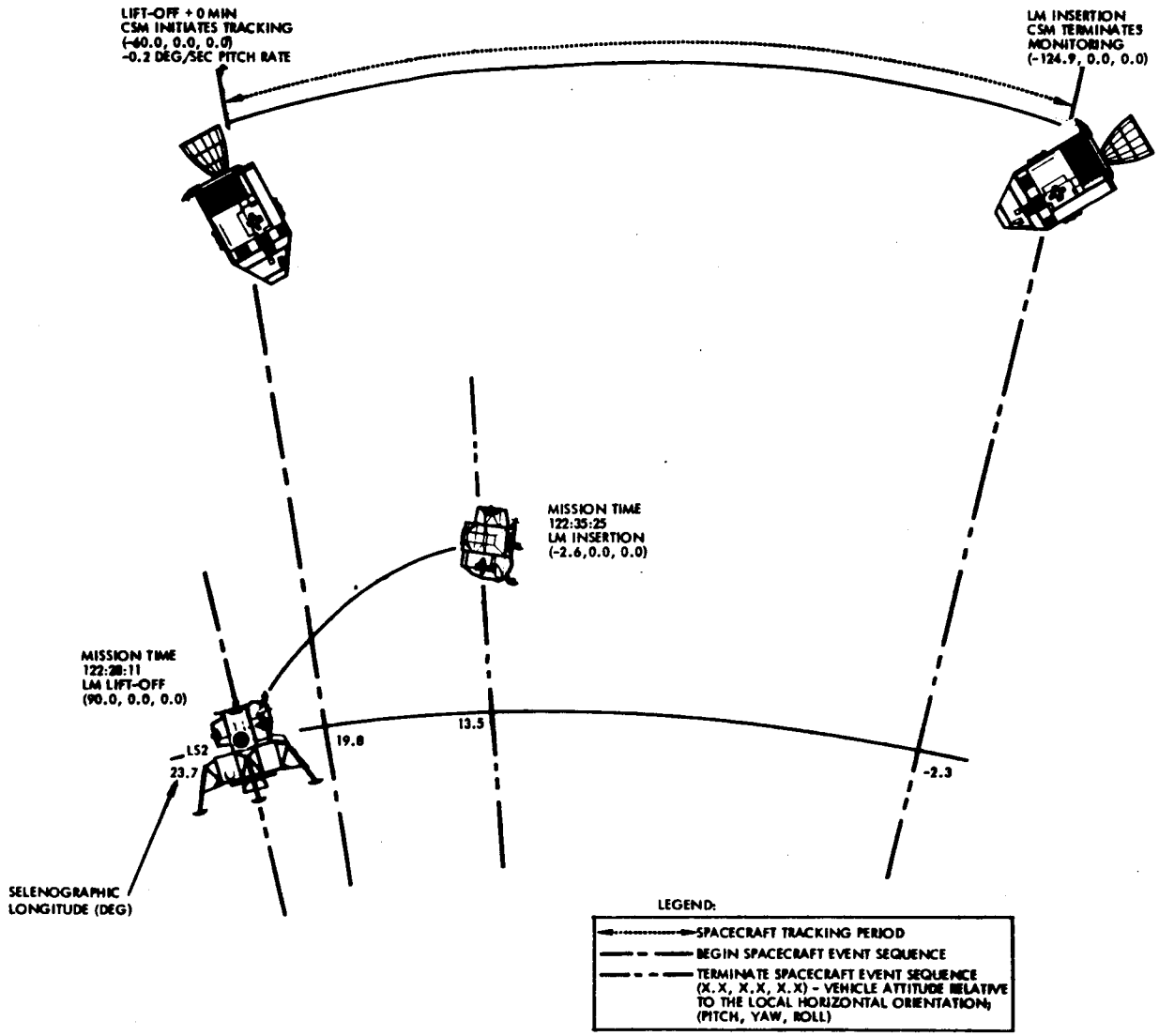

Figure 33. LM Lift-off to Insertion

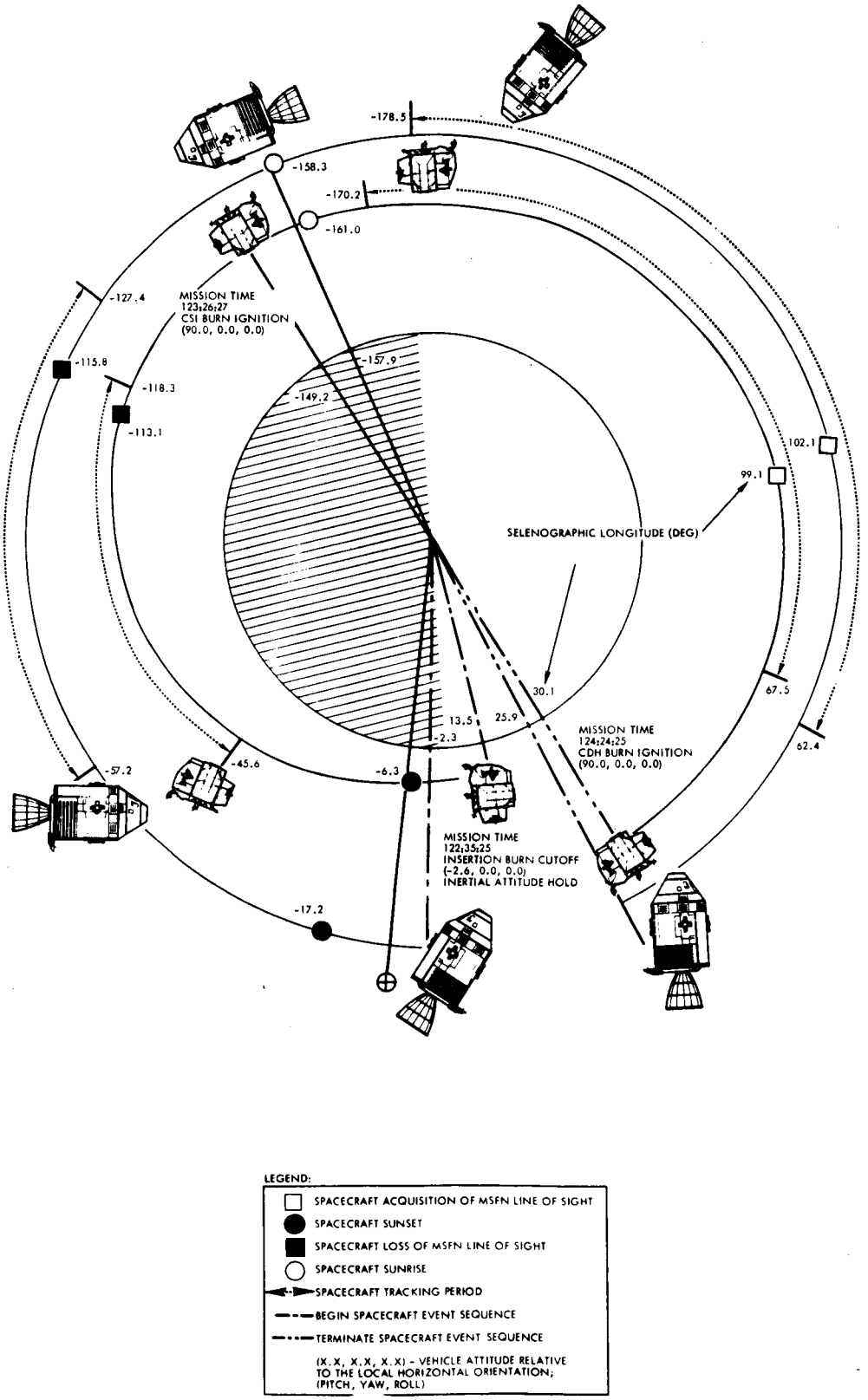

Figure 34. Insertion Burn Cutoff to CDH Ignition

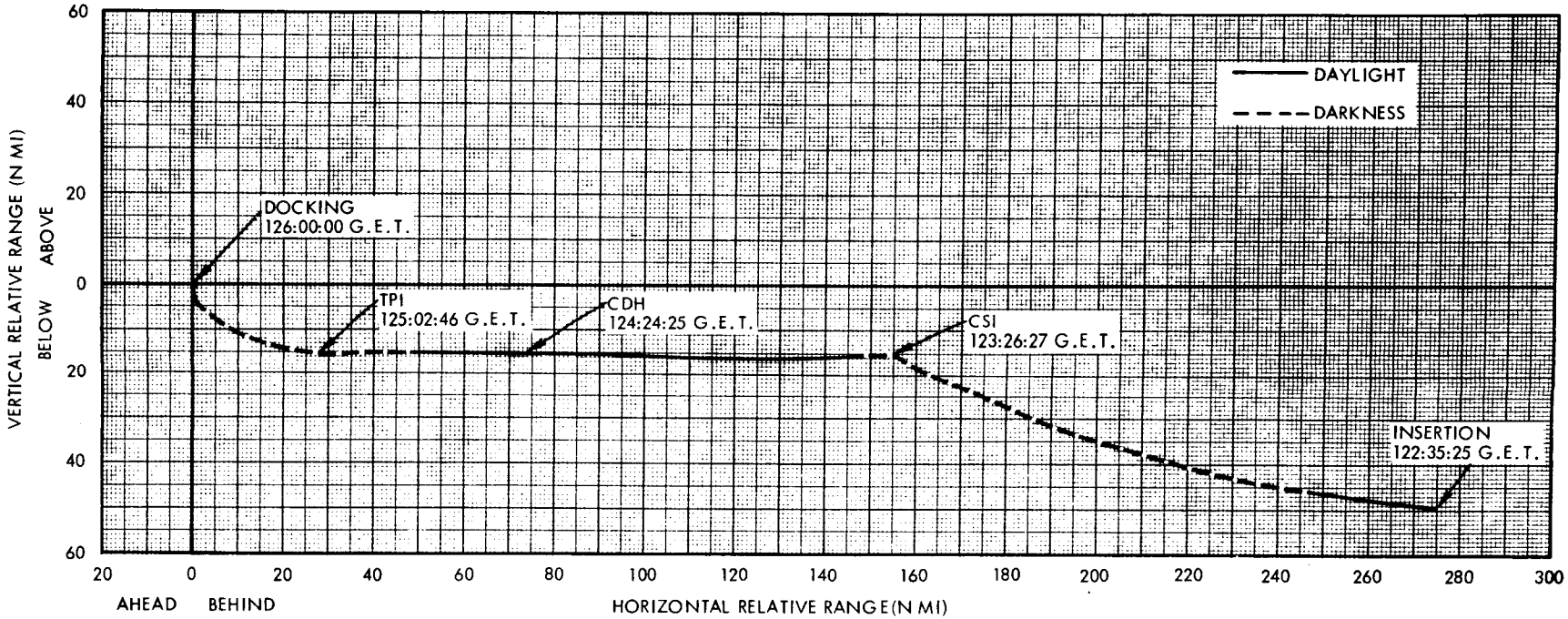

Figure 35. CSM/LM Relative Motion from Insertion to Docking (CSM Fixed)

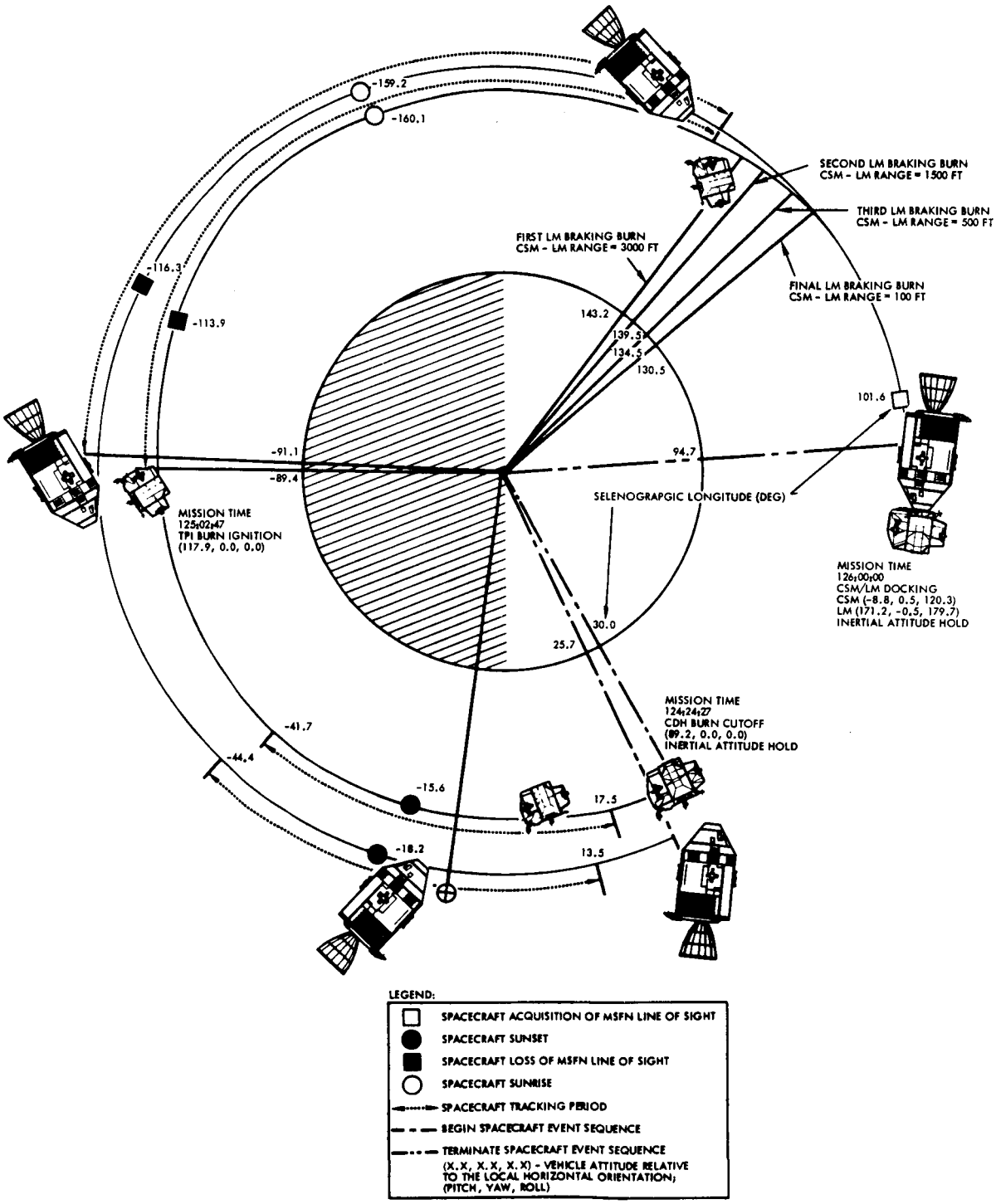

Figure 36. CDH Burn Cutoff to CSM/LM Docking

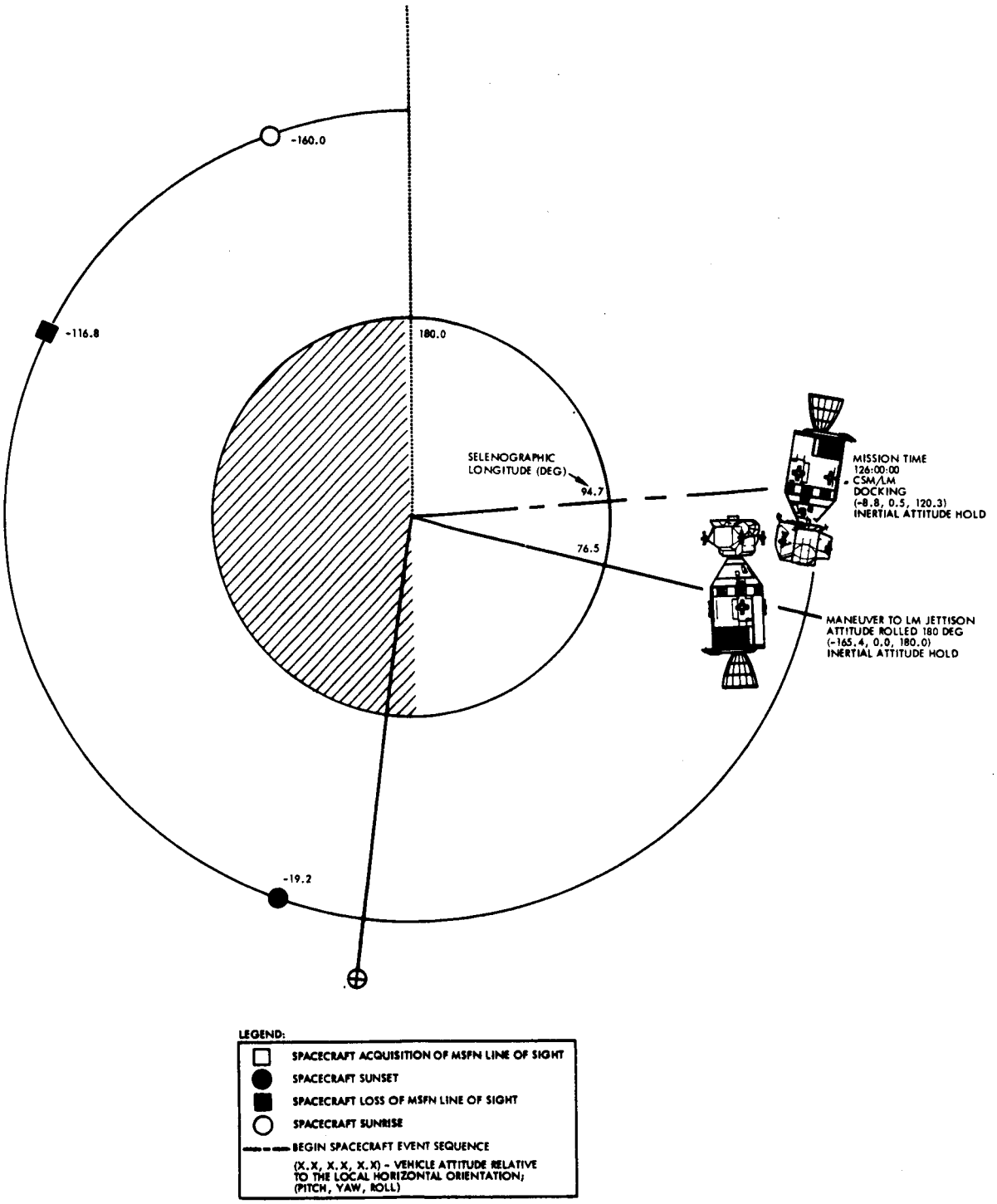

Figure 37. CSM/LM Docking to Completion of Twenty-sixth Revolution

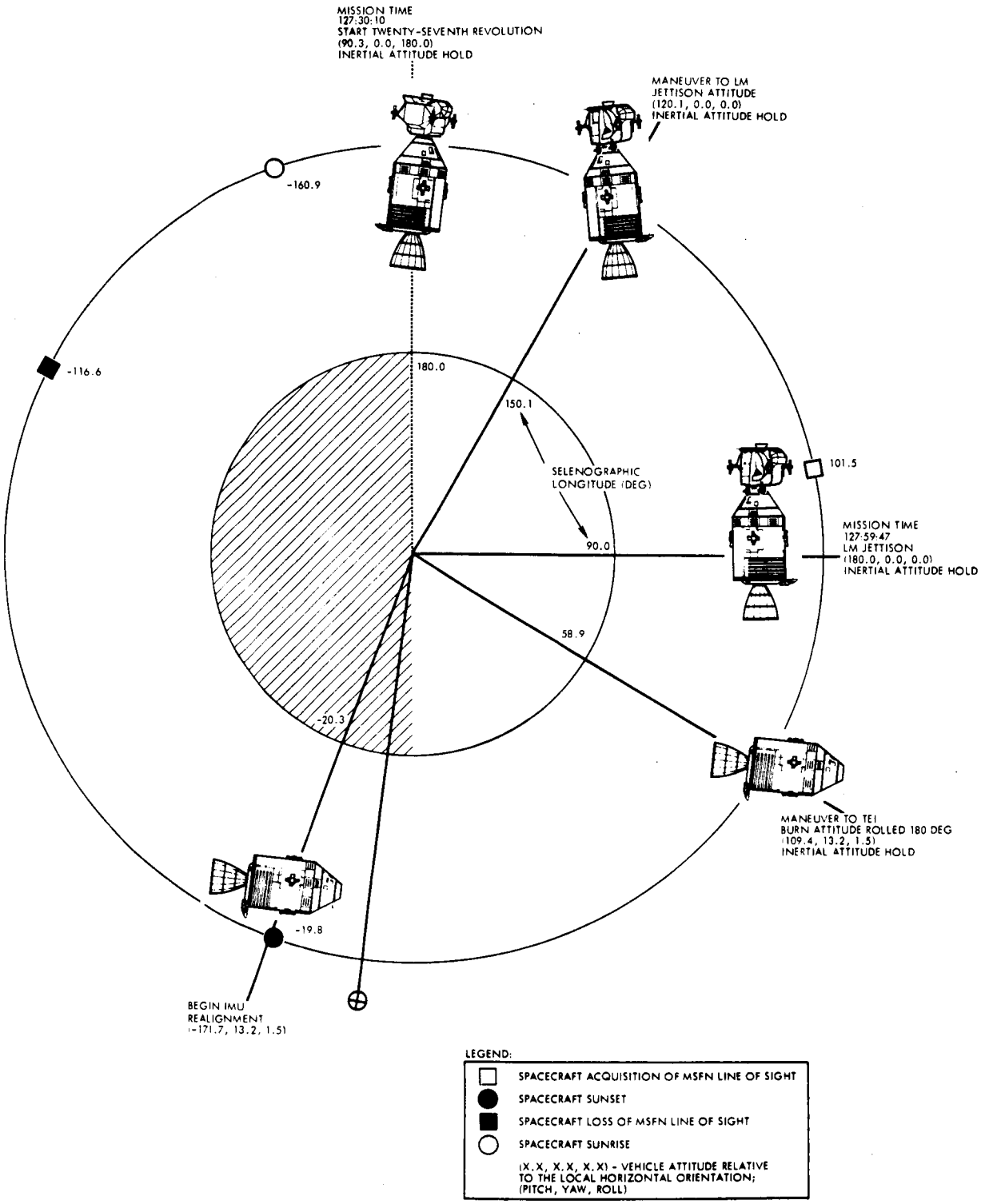

Figure 38. Twenty-seventh Revolution Major Events and Attitude

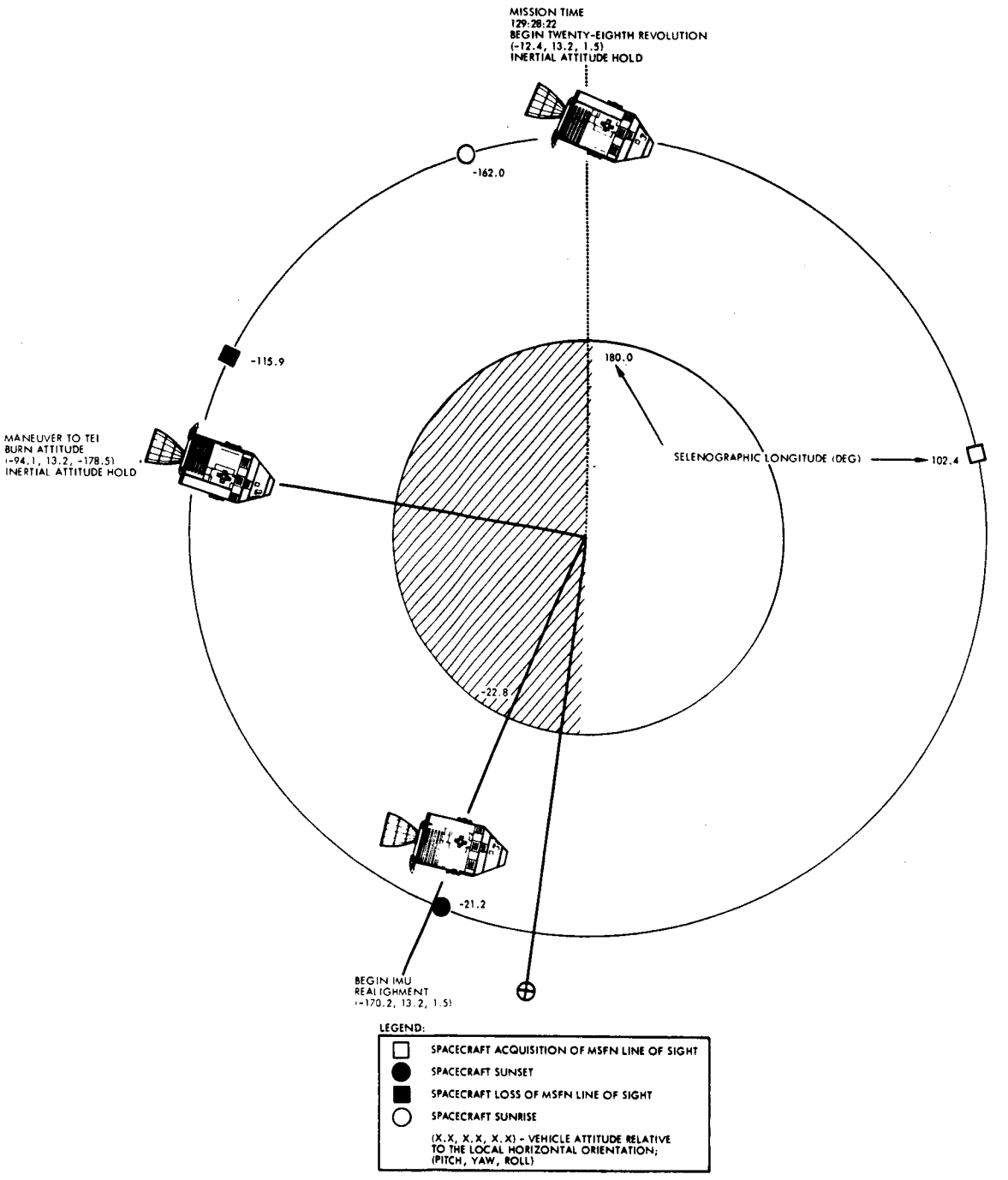

Figure 39. Twenty-eighth Revolution Major Events and Attitudes

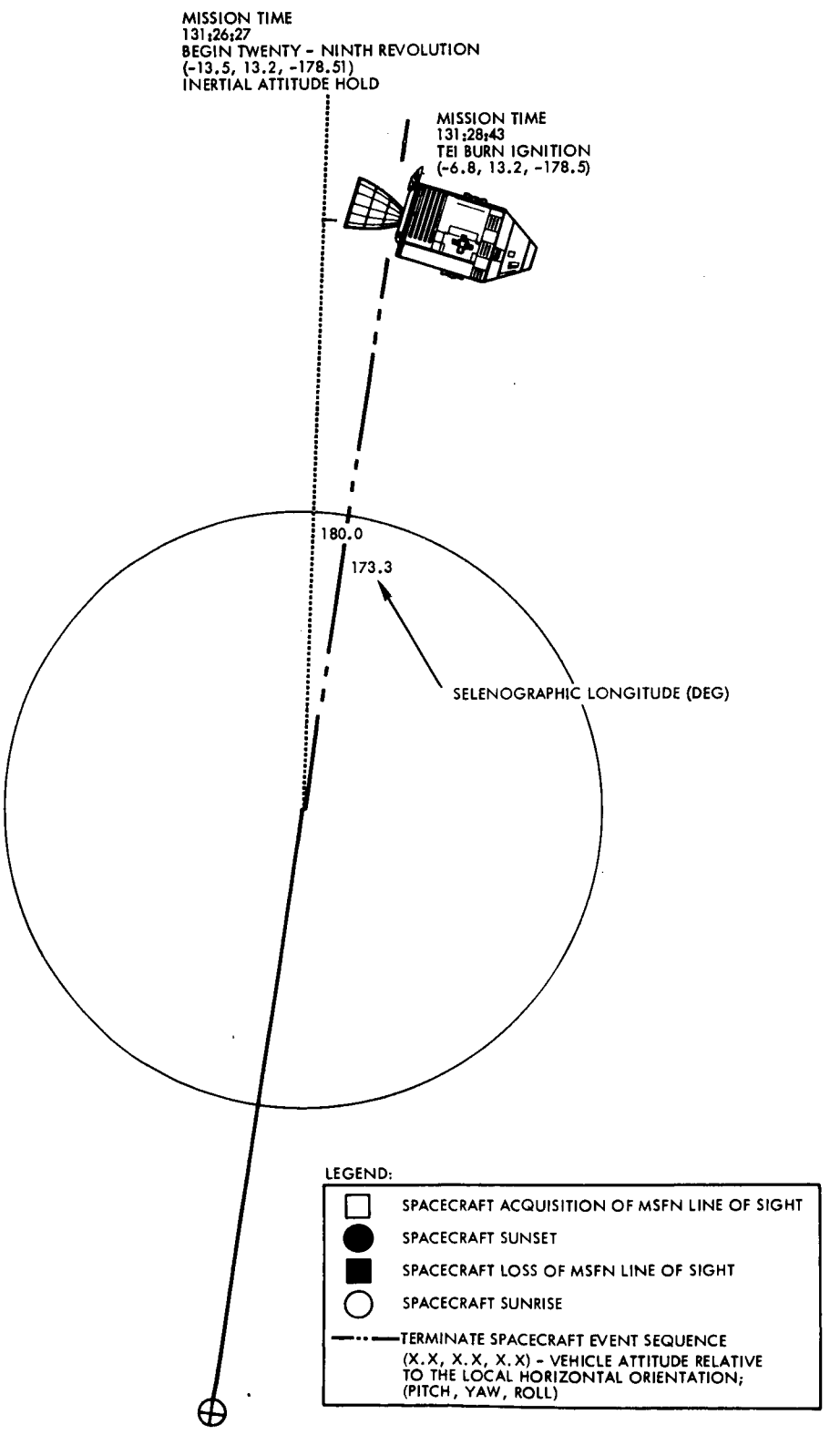

Figure 40. Start of Twenty-ninth Revolution to TEI

REFERENCES

1. Apollo 11 Preliminary Flight Plan (Draft). NASA-MSC Document, April 15, 1969.

2. Schuck, R. B.: Apollo Cislunar and Lunar Orbit Attitude Constraints, Revision 1. TRW Note 69-FMT-526A, February 15, 1969.

3. Hunt, C. R.: Lunar Landmark Tracking Attitude Studies. MSC IN 69-FM-81, April 11, 1969.

4. Mosel, D. K. and Otto, Jr., R. J.: CSM Rendezvous Procedures G1 Mission (Preliminary). NASA-MSC CF-P-69-11, March 15, 1969.

5. Lewis, C. O., Neal, R. T., and Rahman, M. A.: LM Descent/ Ascent Summary Document Mission G (Preliminary). NASA-MSC CF-P-69-16, March 17, 1969.

6. Shreffler, J.: Onboard Tracking Schedules for Mission F and G. MSC Memorandum 69-FM46-29, February 7, 1969.